Grade 6 - Middle School Discipline Specific Core Model

Earth and Space Science

From the introduction to the Middle School Earth and Space Sciences Standards in the NGSS:

> Students in middle school develop understanding of a wide range of topics in Earth and space science (ESS) that build upon science concepts from elementary school through more advanced content, practice, and crosscutting themes. There are six ESS standard topics in middle school: 1) Space Systems, 2) History of Earth, 3) Earth's Interior Systems, 4) Earth's Surface Systems, 5) Weather and Climate, and 6) Human Impacts. The content of the performance expectations are based on current community-based geoscience literacy efforts such as the Earth Science Literacy Principles (Wysession et al. 2012), and is presented with a greater emphasis on an Earth Systems Science approach. The performance expectations strongly reflect the many societally relevant aspects of ESS (resources, hazards, environmental impacts) as well as related connections to engineering and technology. While the performance expectations shown in middle school ESS couple particular practices with specific disciplinary core ideas, instructional decisions should include use of many practices that lead to the performance expectations. (NGSS Lead States 2013b)

A major emphasis of this course is the principle of interacting components of Earth's systems. As noted in the NRC Framework, "The natural and designed world is complex; it is too large and complicated to investigate and comprehend all at once. Scientists and students learn to define small portions for the convenience of investigation. The instructional segments of **investigations** can be referred to as '***systems***.' A system is an organized group of related objects or components that form a whole. Systems can consist, for example, of organisms, machines, fundamental particles, galaxies, ideas, and numbers. Systems have boundaries, components, resources, flow, and feedback (National Research Council [NRC] 2012)."

Although any real ***system*** smaller than the entire Universe interacts with and is dependent on other (external) systems, it is often useful to conceptually isolate a single system for study. To do this, scientists and engineers imagine an artificial boundary between the system in question and everything else. Then they examine the system in detail while treating the effects of things outside the boundary as either forces acting on the system or flows of matter and energy across it—for example, the gravitational force due to Earth on a book lying on a table or the carbon dioxide expelled by an organism. Consideration of flows into and out of the system is a crucial element of system design. In the laboratory or even in field research, the extent to which a system under study can be physically isolated or external conditions controlled is an important element of the design of an investigation and interpretation of results.

Often, the parts of a ***system*** are interdependent – each one depends on or supports the functioning of the system's other parts. Yet the properties and behavior of the whole system can be very different from those of any of its parts, and large systems may have emergent properties, such as the shape of a tree, that cannot be predicted in detail from knowledge about the components and their interactions. Things viewed as subsystems at one ***scale*** may themselves be viewed as whole systems at a smaller scale. For example, the circulatory system can be seen as an entity in itself or as a subsystem of the entire human body; a molecule can be studied as a stable configuration of atoms but also as a subsystem of a cell or a gas.

An explicit model of a system under study can be a useful tool not only for gaining understanding of the system but also for conveying it to others. ***Models of a system*** can range in complexity from lists and simple sketches to detailed computer simulations or functioning prototypes.

The systems identified in the Earth and space sciences course focus are the following:

- Atmosphere: gases around the Earth (i.e., our air)
- Hydrosphere: all the water (sometimes ice is separated out into the cryosphere).
- Geosphere: inorganic rocks and minerals
- Biosphere: all life
- Anthrosphere: humanity and all of its creations (primarily part of the biosphere, but often separated out to emphasize the significant influences humans have on the rest of Earth's systems).

Table 1 provides a schematic organization of the instructional segments and the primary Earth systems discussed in each instructional segment. The *CA NGSS* has titled this discipline Earth and Space Sciences to emphasize that while Earth exists as a singular planet, its systems are strongly influenced by interactions with the broader Universe.

Table 1. Illustration of how different instructional segments relate to Earth's systems.

Instructional segment	Atmos.	Hydro.	Geo.	Bio.	Anthro.
Instructional segment 1: Earth’s Place in the Solar System			X		
Instructional segment 2: Atmosphere: Cycles of Energy	X	X			X
Instructional segment 3: Atmosphere/Hydrosphere: Cycles of Matter	X	X			X
Instructional segment 4: Geosphere, External Processes		X	X	X	X
Instructional segment 5: Geosphere: Internal Processes			X		X

Each of these ***systems*** has components that interact with each other. Modeling the appropriate relationship between these components is at the center of each instructional segment in this course. Further, each system interacts with the others, originating the processes that shape our Earth.

In grade six, students apply and expand their prior understanding of these systems from their science experiences in fifth grade. Thus, beside grade-appropriate proficiency in using all the science and engineering practices and crosscutting concepts, students have developed an understanding of Earth’s major systems (5-ESS2-1; ESS2.A) aided by concepts in physical science (PS1: structure and properties of matter; PS3.D: energy in chemical processes and everyday life) and life science (LS2.B: Cycles of matter and energy transfer in ecosystems). Table 2 shows the disciplinary core ideas that students in sixth grade have experienced in fifth grade or earlier grades. Sixth grade teachers will have to probe using a variety of formative and diagnostic assessment tools the level of familiarity and mastery that their students have as they enter their sixth grade science classes.

Table 2: Disciplinary Core Ideas included in grade 5. Shaded in gray are the core ideas that pertain to Earth and Space Sciences.

Disciplinary Core Ideas	PS1: Matter and Its Interactions	PS1.A: Structure and properties of matter PS1.B: Chemical reactions
	PS2: Forces and Interactions	PS2.B: Types of interactions (gravitational force)
	PS3: Energy	PS3.D: Energy in chemical processes and everyday life
	PS4: Waves and Electromagnetic Interactions	(Addressed in grade 4)
	LS1: From Molecules and Organisms: Structure and Processes	LS1.C: Organization of matter and energy flow in organisms
	LS2: Ecosystems: Interactions, Energy, and Dynamics	LS2.A: Interdependent relationships in ecosystems LS2.B: Cycles of matter and energy transfer in ecosystems
	LS3: Heredity: Inheritance and Variation of Traits	(Addressed in grade 3)
	LS4: Biological Evolution: Unity and Diversity	(Addressed in grade 3)
	ESS1: Earth's Place	ESS1.A: the Universe and its stars

	in the Universe	ESS1.B: Earth and the solar system
	ESS2: Earth's Systems	ESS2.A: Earth materials and systems ESS2.C: the role of water in Earth's surface processes
	ESS3: Earth and Human Activity	ESS3.C: Human Impacts on Earth systems

Earth and space sciences have much in common with the other branches of science, but they also include a unique set of scientific pursuits. Inquiries into the physical sciences (PS2) (e.g., forces, energy, gravity, magnetism) were conducted in part as a means of understanding the size, age, structure, composition, and behavior of Earth, the Sun, and the Moon; physics and chemistry later developed as separate disciplines. The life sciences likewise are partially rooted in earth science, as Earth remains the only example of a biologically active planet, and the fossils found in the geological record of rocks are of interest to both life scientists and earth scientists (LS4). As a result, the majority of research in Earth and space sciences is inter-disciplinary in nature and is often organized into the categories of astrophysics, geophysics, geochemistry, and geobiology. However, the underlying traditional discipline of geology, involving the mapping and interpretation of rocks, remains a cornerstone of Earth and space sciences.

When adapting the *CA NGSS* to their classroom, teachers have great opportunities to make the subject matter regionally relevant. Coastal communities may wish to focus on different spheres of interaction than farming communities in California's Central Valley. Despite these regional differences, large portions of California's students live in densely urban communities where ties to the natural environment are less apparent. When describing possible directions for meeting the PE's, the framework makes efforts to identify directions that will be most relevant for urban youth and mentions specific activities relevant to urban geoscience.

Example Course Mapping for an Earth and Space Science Course

In this section, two types of tables have been included to provide an overview of the materials contained:

1. A summary table: this table provides an overview of the suggested instructional segments identified for this grade level.
2. Separate Instructional segment tables: these tables provide further details of the three dimensions of the *CA NGSS* included in each instructional segment.

Summary table for an example course in Middle School Earth and Space Sciences.

Instructional segment 1: Earth's Place in the Solar System	Performance Expectations addressed		
	MS-ESS1-1 MS-ESS1-2, MS-ESS1-3		
	Highlighted SEP	Highlighted DCI	Highlighted CCC
	• Developing and using models • Analyzing and interpreting data	ESS1.A: The Universe and its stars ESS1.B: Earth and the solar system *Other Necessary DCI*: PS2.B: Types of Interactions	• Patterns • Scale, proportion, and quantity • Systems and system models
	Summary of DCI		
	Patterns of the apparent motion of the sun, the Moon, and stars in the sky can be observed, described, predicted, and explained with models. Galaxies consist of stars, gases, and a collection of objects, including planets, their Moons, and asteroids that are held in orbit by gravitational forces.		

segment 2: Atmosphere: Cycles	Performance Expectations Addressed		
	MS-ESS1-1, MS-ESS2-6, MS-ESS3-4, MS-ESS3-5		
	Highlighted SEP	Highlighted DCI	Highlighted CCC
	• Developing and using models • Planning and carrying out	ESS2.C: The role of water in Earth's surface processes	• Cause and effect • Systems and system models

	investigations • Asking questions and defining problems • Analyzing and interpreting data	ESS2.D: Weather and climate ESS3.B: Natural hazards ESS3.D: Global climate change *Other necessary DCI*: PS3.B: Conservation of Energy and Energy Transfer PS4.B: Electromagnetic radiation	• Patterns •
	Summary of DCI		
	Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise in Earth's mean surface temperature (global warming).		
Instructional segment 3: Atmosphere/Hydrosphere: Cycles of Matter	Performance Expectations Addressed		
	MS-ESS2-4, MS-ESS2-5, MS-ESS2-6, MS-ESS3-3, MS-ESS3-5		
	Highlighted SEP	Highlighted DCI	Highlighted CCC
	• Developing and using models • Planning and carrying out investigations • Asking questions and defining problems • Analyzing and interpreting data	ESS2.C: The role of water in Earth's surface processes ESS2.D: Weather and climate ESS3.B: Natural hazards ESS3.D: Global climate change *Other necessary DCI*: PS3.B: Conservation of Energy and Energy Transfer	• Cause and effect • Systems and system models • Patterns
	Summary of DCI		
	Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation as well as downhill flows on land.		

Instructional segment 4: Geosphere, External Processes	Performance Expectations Addressed		
	MS-ESS1-4, MS-ESS2-1,MS-ESS2-2, MS-ESS3-1, MS-ESS3-2		
	Highlighted SEP	Highlighted DCI	Highlighted CCC
	• Analyzing and interpreting data • Constructing explanations and designing solutions	ESS1.C: The history of planet Earth ESS2.A: Earth's materials and systems ESS2.C: The roles of water in Earth's surface processes Other necessary DCI: LS4.A: Evidence of Common Ancestry and Diversity	• Patterns • Scale, proportion, & quantity
	Summary of DCI		
	The geological time scale interpreted from rock strata provides a way to organize Earth's history.		
Instructional segment 5: Geosphere: Internal Processes	Performance Expectations Addressed		
	MS-ESS2-1,MS-ESS2-2, MS-ESS2-3, MS-ESS3-1, MS-ESS3-2		
	Highlighted SEP	Highlighted DCI	Highlighted CCC
	• Analyzing and interpreting data • Constructing explanations and designing solutions	ESS1.C: The history of planet Earth ESS2.A: Earth's materials and systems ESS2.B: Plate tectonics and large-scale system interactions Other necessary DCI: LS4.A: Evidence of Common Ancestry and Diversity	• Patterns • Scale, proportion, & quantity
	Summary of DCI		

	Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding the geological history.

Grade 6 Instructional segment 1: Earth's Place in the Solar System

Instructional segment 1: Earth's Place in the Solar System
Guiding Questions: • What causes the patterns and cycles of stars, planets, and the moon? • How can we represent the vastness of the solar system and compare objects as large as planets and moons?
Highlighted Scientific and Engineering Practices: • Developing and using models • Analyzing and interpreting data
Highlighted Cross-cutting concepts: • Scale, proportion and quantity • Cause and Effect
Students who demonstrate understanding can: **MS-ESS1-1. Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons.** [Clarification Statement: Examples of models can be physical, graphical, or conceptual.] **MS-ESS1-2. Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.** [Clarification Statement: Emphasis for the model is on gravity as the force that holds together the solar system and Milky Way galaxy and controls orbital motions within them. Examples of models can be physical (such as the analogy of distance along a football field or computer visualizations of elliptical orbits) or conceptual (such as mathematical proportions relative to the size of familiar objects such as their school or state).] [Assessment Boundary: Assessment does not include Kepler's Laws of orbital motion or the apparent retrograde motion of the planets as viewed from Earth.] **MS-ESS1-3. Analyze and interpret data to determine scale properties of objects in the solar system.** [Clarification Statement: Emphasis is on the analysis of data from Earth-based instruments, space-based telescopes,

and spacecraft to determine similarities and differences among solar system objects. Examples of scale properties include the sizes of an object's layers (such as crust and atmosphere), surface features (such as volcanoes), and orbital radius. Examples of data include statistical information, drawings and photographs, and models.] [Assessment Boundary: Assessment does not include recalling facts about properties of the planets and other solar system bodies.]
Significant Connections to California's Environmental Principles and Concepts: None

Background and instructional Suggestions

People throughout history have been fascinated by the heavens. Each ancient civilization noticed ***patterns*** in the movement of the Sun, Moon, and stars. Students themselves have recognized and described patterns of motion in the sky in earlier grades (***1-ESS1-1***, ***5-ESS1-2***). Teachers can begin by reviewing those patterns, perhaps working with ELA teachers to read stories about the way in which ancient civilizations used the patterns in the stars to predict their motion. In this instructional segment, students construct **models** that explain the size, shape, and timing of these motions. Students should, like the people from ancient civilizations, be able to apply these models to qualitatively predict the motions of objects. In high school, they will extend this model by adding quantitative descriptions of the forces that cause the motion. Sixth grade lays the crucial foundation for that work.

Gravity is the driving force that shapes most of the motion in the Universe. In third grade, students investigated gravity as a force that can pull objects downward (3-PS2-1). If that's the case, why doesn't the moon fall down?[1] How can a force that pulls an object downward give rise to the ordered ***patterns*** we see in the movement of the stars in the sky? In this instructional segment, students **develop a model** of this process (*MS-ESS1-2*). Essential components of the model are 1) gravity is a force that pulls massive objects towards one another; 2) objects in the solar system move in

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[1] NASA Ask an Astronomer, Why doesn't the Moon fall down, http://www.spitzer.caltech.edu/video-audio/62-ask2002-001-Why-Doesn-t-the-Moon-Fall-Down-

circular patterns around the Sun and stars in galaxies move in circular patterns around their center. Students can illustrate the relationship between these ideas with a rope (left side of Figure 1). One person stands in the center and holds the rope while the other starts moving away. Once the rope is taught, both people feel the rope tugging them together. The pull of the rope changes the moving person's direction, constantly pulling that person back on course so that he or she moves only in a circular motion. Isaac Newton developed a conceptual model of this with the idea of a cannon shot from a tall mountain at different speeds. Gravity always pulls the cannon ball down, but the direction of "down" changes constantly (just like the *direction* of pull from the rope changes constantly as the student runs around the circle). Online interactive simulations of Newton's cannon can help students visualize the model even better.

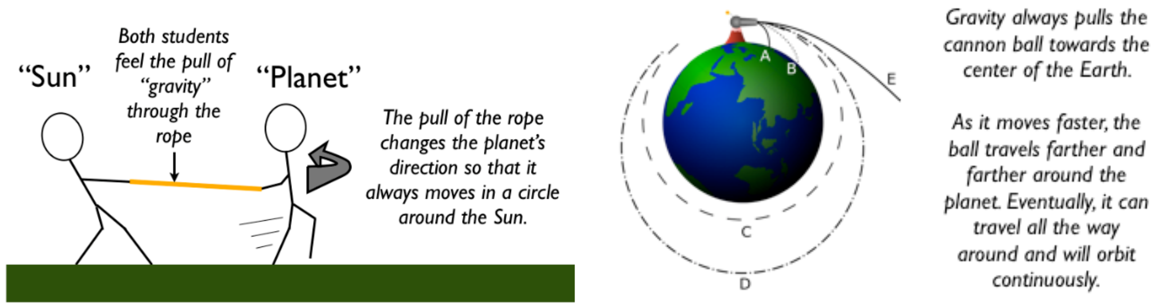

Figure 1. Models showing the relationship between gravity and the circular motion of objects in orbits. The left side is a physical model with students representing planets. The right side shows Newton's cannon, a conceptual model illustrated in a diagram. Image Credit: (CC-BY-NC-SA) by Matthew d'Alessio (LEFT) and Brondel 2010

The clarification statement for *MS-ESS1-2* may cause confusion, since many of the examples given pertain to ***scale*** **models** for *MS-ESS1-3*. The two PE's are intricately connected because gravity and motion help define the shape and scale of recognizable bodies in our solar system. The next section describes some of these relationships.

Common Core Connection: Solar system scale

When pondering Earth's place within the solar system, ***scale and proportion*** are repeating concepts, and they align well with the **mathematical thinking** about ratios and proportions from 6th grade mathematics (*CA CCSSM6.RP.1*). NASA has a series of activities on Solar System math that allow students **analyze data** about solar system ***scale*** and then build scale **models**[2]. The activity from Day 1 in the vignette below is a related example pertaining to the Moon. Students also can get a tangible sense of the relative scale of the solar system by constructing a scale model on a 100 yard football field. Most of these examples provide solar system sizes as numbers in tables, but the clarification statement for *MS-ESS1-3* identifies another of other ways that students can obtain their **data for analysis**, including photographs, drawings, and models. For example, students can use online interactive models of the solar system to record the orbital distance and period of different planets. As the distance from the Sun increases, the time it takes for the planet to complete one orbit also increases. A similar activity can be done using a virtual telescope to analyze the orbital distance and orbital period of the moons of Jupiter[3]. A motivation for choosing to investigate orbital periods and radii is that it prepares students for calculating orbital periods using Kepler's Laws in high school (*HS-ESS1-4*).

Patterns in the Sun-Earth-Moon system

The study of the moon under the *CA NGSS* illustrates some of the shifts in expectations compared to the 1998 California standards. Under the 1998 standards, 3rd grade students should **know** "the way in which the Moon's appearance ***changes*** during the four week lunar cycle." In the *CA NGSS*, students use observations to describe ***patterns*** in the moon's motion in 1st grade (*1-ESS1-1*). Explaining the moon's appearance is now part of 6th grade, but the emphasis is on **developing a model** that students can use to make and test predictions instead of simply describing the phases (*MS-ESS1-1*). The vignette below illustrates a teaching sequence that helps accomplish this model development.

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[2] NASA, Solar System Math: http://quest.nasa.gov/vft/#wtd

[3] An older software package is here: Project CLEA: http://www3.gettysburg.edu/~marschal/clea/juplab.html, but a more modern version could be produced.

Middle School Vignette

Using Models of Space Systems to Describe and Explain Patterns of Moon's Phases

(Adapted from NGSS Lead States 2013a, Case Study 3)

The vignette presents an example of how teaching and learning may look like in the classroom when the *CA NGSS* are implemented. The purpose is to illustrate how a teacher engages students in three-dimensional learning by providing them with experiences and opportunity to develop and use the science and engineering practices and the crosscutting concepts to understand the disciplinary core ideas associated with the topic in the instructional segment.

It is important to note that the vignette focuses on only a limited number of performance expectations. It should not be viewed as showing all instruction necessary to prepare students to fully achieve these performance expectations or complete the instructional segment. Neither does it indicate that the performance expectations should be taught one at a time.

The vignette uses specific classroom contexts and themes, but it is not meant to imply that this is the only way or the best way in which students are able to achieve the indicated performance expectations. Rather, the vignette highlights examples of teaching strategies, organization of the lesson structure, and possible students' responses. In addition, science instruction should take into account that student understanding builds over time and that some topics or ideas require activating prior knowledge and extend that knowledge by revisiting it throughout the course of a year.

Introduction

The students in Mr. O sixth grade classroom receive science instruction five days a week for 50 minutes each day. The students also receive instruction in reading/language arts and mathematics in an integrated fashion. Strategic grouping of students provides opportunities for peer-to-peer collaboration, facilitating support for struggling students, including English Language Learner students.

In the lesson sequence in this vignette, Mr. O uses multiple means of representations for allowing students to make sense of the view of the Moon phases as seen from Earth. These representations include: computer models using planetarium software (available free online[4]), physical models (foam balls, a lamp, golf balls), and diagrams such as foldables (three-dimensional interactive graphic representations with templates available online). Engaging the students in these multiple experiences to explain the same phenomenon and allowing them to **develop their own models** or evaluate alternative representations of the same model facilitates students' development of a conceptual model of the Earth-Sun-Moon system. In addition, the multiple experiences support language development as students discuss and **ask questions** about the experiences.

Mr. O has been preparing for this instructional segment for the past four months and he had strategically alerted students to look at the Moon in the sky throughout multiple days and notice changes in what they saw. Also, he often started the day by showing pictures of the Moon he had taken with his cell phone or had found online and had posted those picture in a corner of the classroom with a label indicating date and time. Most of the students knew already that the Moon appears different across different days of the month. Most of them, however, had not observed the Moon during daytime and they were surprised when Mr. O pointed out to the Moon in the sky one morning while they were playing in the playground before class. This preparation increased students' interest and everybody was excited when Mr. O announced, "Today we are going to learn about the Moon."

Day 1 - Exploring the Earth-Moon-Sun relationship.

Mr. O initiated the instructional segment by asking students to open their notebooks, write the numbers 1-8 down the next blank page, and title it "Relative

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[4] Stellarium: http://stellarium.org

Diameters." On the interactive whiteboard, he projected a slide from a multi-media presentation *Two Astronomy Games* that showed nine images each identified by a letter and a label (Morrow 2004). The images were the Sun, Earth, a space shuttle, the Moon, the solar system, Mars, a galaxy, and Jupiter. Students were asked to number the objects in order from smallest (number 1) to largest (number 8) and from nearest to the surface of the Earth to farthest from the surface of the Earth. As the students marked their choices on their own, Mr. O walked among the students' tables to gain insight regarding their prior knowledge. He planned to have students come back to this page later. Kevin, one of the most talkative students, seemed pleased and announced, "I love to study space!"

Mr. O moved to the front of the classroom and picked up a standard-sized playground ball in his hand. He asked the class to imagine the ball was Earth and he wrote down the class' consensus of the ball's dimensions that they had measured in math class. The diameter of the ball was 42 cm. Then he presented the class with a box of seven balls in a variety of sizes and listed their dimensions on the interactive whiteboard. He asked: "If Earth was the size of this playground ball, which of these balls would be the size of the Moon?" One student (from each table) came up and chose the ball they thought would be correct. Their choices varied from a softball to a small marble.

Before going further, the class reviewed the term diameter and Mr. O asked, "If you know that Earth's diameter is 12,756 kilometers and the Moon's diameter is 3,476 kilometers, with your table groups, come up with a method to see if the ball you chose is the right size for this size Earth (holding up the playground ball)." (**using mathematics and computational thinking**) (***scale, proportion, and quantity***) (*CA CCSSM .6.RP.1)*

After some discussion time, students reported their calculations. One group noticed that there was a proportional relationship in the diameters of approximately 1:4, Earth to Moon. A student asked how they made that determination. Jeff responded, "If you estimate using 12,000 and 3,000, three goes into twelve four times." He showed on the interactive whiteboard how four circles of a Moon model fit across the diameter of an Earth model. Mr. O said, "Now look at your ball as a Moon model and decide if you think it is the correct size. What can you do to be sure? Decide on a process." He let them use the playground ball as needed. (*MS-ESS1.A*)

Each group reported their findings and methods for determining whether or not their choice would be correct. One group made lines on paper where the endpoint of their ball was and did the same for the playground ball. Using those measurements and the 1:4 ratio, they decided if their Moon was the correct size. Another group used string to measure the diameter of the balls and then determined whether or not it was correct. Still another group held their ball up against the playground ball and moved their ball four times while marking the playground ball with a finger to see if their ball was the correct size for the model of Earth.

All groups reported their findings to the classroom. Kevin was agitated as he explained, "I told my group they were not right. The racquetball is the only one that is possible as the Moon, but they wouldn't believe me." Mr. O asked Kevin to restate the rule for when his group disagrees. Kevin thought and said, "When my group disagrees, I listen and then tell them what I think." The classroom came to a consensus that the racquetball was the correct size ball to represent the Moon for the playground ball to represent the Earth.

Day 2 - Exploring the Earth-Moon-Sun relationship.

On the next day, Mr. O showed the students the actual distance from Earth to the moon and the circumference of Earth in kilometers. He asked them to figure out the distance between Earth and Moon in the model and to show it using string. Students were shocked at the distance the Moon was from Earth in this model. Their estimates had been much lower.

The class continued this activity by choosing correct size balls for the sun and Earth. Students also considered the relative size of the Sun and the distance of the Sun from Earth in the model. They used the **evidence** of the diameter of the Sun and its distance from Earth in the same way they determined the size and distance of the Moon from Earth. Some students were surprised at the size of the Sun and its distance from Earth in this model. Jeff decided that they could not fit the Sun in the room. He explained that it would take over 100 playground balls to approximate the Sun's diameter. Jeff was eager to share his mathematical skill at finding the answer: "I know the answer! It would take almost 12,000 playground balls lined up to show how far away the Sun would be in this model." (***scale, proportion, and quantity***)

The students returned to their initial ideas on the "Relative Diameters" page in their notebooks, renumber the objects, and write any ideas that had changed after making the model. After giving students time to record their responses, Mr. O showed images of the items on the interactive whiteboard and led a discussion of the great distances between objects in the solar system in preparation for modeling the Moon's phases. (MS-ESS1.B)

Day 3 - Exploring Moon phases: Computer representation

For this lesson sequence, Mr. O considered the make-up of the table groupings of students. He wanted all students to have support while determining methods to check their choice of the Moon model, so he grouped students with that concern in mind. He used physical representations of Earth and the Moon and had students represent the distance physically, thereby assisting them in visualization and comprehension.

Mr. O downloaded an open-source planetarium software onto his interactive whiteboard- connected computer as well as onto the 14 student computers he had in his classroom. Each student also received a one-page calendar and they were instructed to use it to collect data using the software. Mr. O launched the program on the interactive whiteboard, introduced the students to the software, and showed them how to change the date and set up the scale Moon so they could see the phases. Mr. O also showed how the Moon's and Earth's orbital planes are offset by 5 degrees in an effort to help students understand how light can illuminate the Moon when it is on the other side of Earth without being blocked by Earth's shadow.

Recording began on the first Sunday on the calendar and ended on the last Saturday, resulting in five weeks of **data to analyze** (**analyzing and interpreting data**) Mr. O modeled how to record the data on the whiteboard next to the interactive whiteboard. Students recorded the time and direction of moonrise and moonset as well as the apparent shape of the Moon in the sky for each date. To make sure that students understood the process and were recording accurately, he walked through the room and checked student work throughout the lesson.

During this data collection process, the students were told to focus their attention to the Sun-Moon relationship so they could see the light from the Sun traveling in a straight line to the Moon. The Moon was in the sky as the Sun was rising, and they focused on the Moon so that they could use the model for predictions. Mr. O asked, “Does anyone know where the Sun is right now?” Brady responded, “It’s more to the east and still rising.” Using the time and date function in the program, Mr. O advanced the time to show the sunrise and said, “Look at the Sun and Moon. What pattern do you notice about the light on the Moon in relation to the Sun?” (***Patterns***) Hillary answered, “It is going from the Sun to the Moon.” Mr. O responded, “Hmm. The light travels in a straight path from the Sun to the Moon. You have already learned that light travels in a straight line. Can we use that information to predict the position of the Sun even if we can’t see it? Let’s try as we continue.” After collecting six days of data, Mr. O asked students to look at the pattern in their data and predict the time and direction for moonrise and moonset on the next day. Bringing their attention to the patterns in the data he asked, “What time do you think the Moon will set on this day? The last time was 12:09.” Mark said, “I think 12:59.” Mr. O advanced the time in the software until the moonset – at 13:08. Jeff called out, “So it is setting about an hour later each time.” To reinforce the language Mr. O will use on many occasions throughout the instructional segment the following question, “What does that tell us about the planets and the Moon? They all move…” and students responded, “…in predictable patterns.”

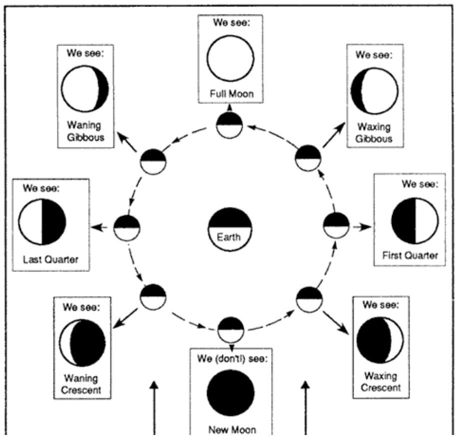
A student said, “So let’s see if that ***pattern*** continues the whole month.” Once Mr. O was satisfied that the students had a foundation for data collection and that they were not just copying numbers from the software into their worksheet calendar, he told them to move to their computers in partners so they could work more independently to complete the data collection on the calendar. The students continued to record data about sunrise and moonrise until all the days in the handout calendar were filled.

Day 4 – Exploring moon phases: Physical representation

After students worked at the computers to complete the calendar, Mr. O started a related activity in which they modeled Moon phases using Styrofoam balls, their heads, and a lamp with a bare bulb. In small groups students stood in a circle around a lamp representing the Sun, holding a Styrofoam ball on a stick representing the Moon. They held the ball at arm's length and rotated their bodies using their heads as a representation of Earth so they could see the earth view of the Moon in all its phases in the lit portion of the ball. Mr. O directed Nicole to look at the Styrofoam ball and the changing shadow. "What? I don't see the shadow." Mr. O pointed out the curve of light on the Moon. "I see it!" Nicole said. The students went through the phases, making a drawing in their notebook and naming each one. Small groups allowed Mr. O to make sure that all students could see the lit portion on the Styrofoam balls for each phase and were able to accurately illustrate the phases in the model, giving him the opportunity to physically move them into position as necessary. He frequently checked with students in the groups to show him to reproduce the position of the Styrofoam ball corresponding to the drawings in their notebook.

For this activity, Mr. O expected all students to observe that the lit segment of the Moon's face increased, decreased, and increased again relative to the part in shadow. He also expected students to notice that the lit side of the Moon was on the left after the full Moon phase, and on the right after the new Moon phase, as viewed from Earth.

Day 5-7 – Developing a model to explain the Moon phases.



The next day, Mr. O pulled out large whiteboards and instructed the students to collaborate and make a drawing to explain how the model of the Moon phases illustrated changes in the apparent shape of the Moon. Mr. O started the lesson telling students they were going to make their thinking public by producing small group models. Students first organized their individual understanding by sketching and labeling the apparent changes in the moon based on what they observed and discussed in class. Next they took turns sharing their ideas with their group, noting similarities and differences. Mr. O walked the classroom listening to the progress as each group member shared. He reminded some groups of the classroom norms of respect and responsibility when participating in a group discussion. After reaching a consensus on the elements the group believed explained the apparent changes in the shape of the moon, they acquired a large whiteboard and produce a group consensus model to share with the class. They discussed limitations of the **models** – the things that a model is unable to show accurately. For example, the students identified the relative sizes of the Sun, Earth, and Moon as well as the relative distances between each as being inaccurate in this model. They had learned that in the previous days.

The following day, Mr. O announced they were doing a “Sticky Note” gallery walk of the models where each group would visit each of the models, consider and discuss them and then provide feedback on a color coded sticky note. Three different colors were used; one for questions, one for additions and one for suggested revisions. Students were reminded that the purpose of the feedback was to help the authors clarify the thinking that went into their model. Mr. O provided sentence frames to help students form questions, additions or suggested revisions. As the groups walked and discussed the use of the color-coding helped to focus their discussion and make it productive.

After completing the gallery walk, each group organized the sticky notes they received by the type of comment and then made revisions to their model based on the feedback.

Over the next two days Mr. O again pulled small groups of students to use another **physical model** showing Moon phases. This one used golf balls that were painted black on half of the sphere, leaving the other half showing the side of the Moon lit by the Sun (Young and Guy 2008). The golf balls were drilled and mounted on tees so they would stand up on a surface. Mr. O had two sets – one set up on a table that showed the Moon in orbit around the earth in eight phase positions as the "space view" model (Figure 1), and the other with the model Moons set on eight chairs circled in the eight phase positions to show the "earth view" model (Figure 2).

Figure 1. Space view model

First, students were shown the space view model and asked what they noticed about the Moons. Mr. O wanted them to notice that the white sides of all the balls (showing light) faced the same direction. He asked them to identify the direction of the Sun. Then Mr. O drew the students' attention to the model on the chairs, the earth view model. All the balls in this model faced the same direction as those in the space view model. Students again identified the direction of the Sun and noted that the position of the Moons in both **models** was the same (MS-ESS1.A). One at a time, students physically got into the center of the circle of chairs and viewed the phases at eye level, which simulated the earth view of each phase. Also, students compared their drawing on the whiteboard illustrating the model of the Earth-Sun-Moon system with what they were seeing now. This activity made the diagram, often found in books and worksheets showing both views on the same diagram, less confusing to the students.

Throughout the lesson sequence, Mr. O continually formatively assessed students' progression of learning through observations and classroom discourse. If he noticed students needed more experience with Moon phases, he provided them with additional activities such as videos and Moon phase cards. In one formal assessment of understanding, Mr. O paired students together so that one was assigned to be the earth and the other the Moon. He designated one wall of the classroom as the Sun and then asked the Moons to show different phases. The students switched roles so that Mr. O could assess everyone. He also used this model to demonstrate the Moon's coincident rotation and revolution. In another formal assessment, he asked students to draw a model on whiteboards showing the relationship of the earth, Moon, and Sun in full Moon phase.

Day 8 – Solidify learning about Moon phases and extend learning through readings.

Mr. O brought all students together the next day to create a foldable showing the earth view of the Moon phases similar to diagrams found in books. Students created their Moon phases using eight black circles and four white circles, cutting the white circles to make two crescent Moons, two gibbous Moons and two-quarter Moons. The white circle pieces were placed on the black circles to create the phases, and later glued on the foldable.

Students partnered to read *The Moon* by Seymour Simon (2003). Students used the **information** in the book to label the Moon phases on their foldable, write about the Moon's surface, and record any new **questions** that arose from their reading. Kevin asked, "When is the next solar and lunar eclipse?" Jeanette questioned, "What samples were brought back from the Moon?" And Nicole wanted to know, "Where did Americans land on the Moon?" To support their reading of the text, the teacher gave Hillary, Brady, and Jeff the option of being paired with students who had more advanced reading skills. The teacher allowed students who finished with the entire reading task to use text materials and Internet resources to research answers to the questions they developed when reading *The Moon.* The teacher will use these answers to these questions during the next few days. For example, Mr. O may have students revisit the physical model of the Earth-Sun-Moon system to explain solar and lunar eclipses (*MS-ESS1-1*).

NGSS Connections and Three-Dimensional Learning

Performance Expectations

MS-ESS1-1 Earth's Place in the Universe

Develop and use a model of the Earth-sun-moon system to predict and describe the cyclic patterns of lunar phases, eclipses of the sun and moon, and seasons.

MS-ESS1-3 Earth's Place in the Universe

Analyze and interpret data to determine scale properties of objects in the solar system.

Science and engineering practices	Disciplinary core ideas	Cross cutting concepts
Developing and Using Models *Develop and use a model to describe phenomena.* **Analyzing and Interpreting Data** *Analyze and interpret data to determine similarities and differences in findings*	**ESS1.A The Universe and Its Stars** *Patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models.* **ESS1.B Earth and the Solar System** *The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them. This model of the solar system can explain tides and eclipses of the sun and the moon.*	**Patterns** *Patterns can be used to identify cause-and-effect relationships* **Scale, Proportion, and Quantity** *Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.*

Connections to the CA CCSSM: MP. 1, MP. 2, MP. 3

Connections to CA CCSS for ELA/Literacy: RI.7, RI.8, SL.8.1, SL 8.2, RST.6-8.2, RST.6-8.3
Connection to CA ELD Standards: ELD.PI.8.1, ELD.PI.8.5, ELD.PI.8.6a-b,

Vignette Debrief

The *CA NGSS* require that students engage in science and engineering practices to develop deeper understanding of the disciplinary core ideas and crosscutting concepts. The lessons give students multiple opportunities to engage with the core ideas in space science (moon phases), helping them to move towards mastery of the three components described in the *CA NGSS* performance expectation.

In this vignette, the teacher selected two performance expectations and in the lessons described above and he engaged students only in selected portions of these PEs. Full mastery of the PEs will be achieved throughout subsequent instructional segments.

Students were engaged in a number of science practices with a focus on **developing and using models** and **analyzing and interpreting data**. Space science lends itself well to the use of models to describe ***patterns*** in phenomena and to construct explanations based on **evidence**.

With guidance from their teacher, students used the ratios of the diameters of Earth and its moon to construct a class model of the relative sizes of the two objects. Using distance and Earth's diameter or circumference ratios, they also constructed a distance model of those objects. In addition, the relative size of the Sun and the relative distance from Earth in this model was calculated and described, although not constructed (due to the constraints of the room and location). Throughout the vignette, a variety of **models** were used to help students identify ***patterns*** in the relative positions of the Earth, Moon and Sun, and to explain moon phases.

Students made predictions about the data collected and recorded them on the calendar, using the lens of the crosscutting concept of ***patterns***. When analyzing and **interpreting the data**, they identified the patterns in the Earth-Moon-Sun relationship. The pattern made by the lit portion of the moon was observed and recorded. In addition, students considered the crosscutting concept of ***scale, proportion, and quantity*** as they constructed **models** of relative sizes and distance of the sun and planets.

CCSS Connections to English Language Arts and Mathematics

Students are engaged in small group work activities, both listening to their peers ideas and sharing their own thoughts. Students used the text in *The Moon Book* to label each phase of the Moon in their graphic organizer foldable. This connects to the *CA CCSS for ELA/Literacy* Reading Informational Text standard (RI.7). In addition, they summarized information about the surface of the moon inside their foldable, which corresponds to Reading Informational Text Standard 8 (RI.8).

When comparing sizes and distances, students were challenged to find ways of comparing numbers, applying the CA CCSSM Standard for Mathematical Practice 1 (MP.1). In addition, students used rounding and estimation to calculate the quotients in the ratios, both skills developed in earlier grades. Throughout the instructional segment, students reasoned quantitatively as they compared the sizes of the Earth and Moon, Standard for Mathematical Practice 2 (MP.2). As students made conclusions about which ball was the moon, they argued for their selection and agreed or disagreed with each other using their calculation, Standard for Mathematical Practice 3 (MP.3)

MP.1 Make sense of problems and persevere in solving them.

MP.2 Reason abstractly and quantitatively.

MP.3 Construct viable arguments and critique the reasoning of others.

Resources for the Vignette

- Morrow, C. 2004. Two Astronomy Games. http://www.spacescience.org/education/instructional_materials.html (accessed August 5, 2015).
- Simon, S. 2003. *The Moon*. New York, NY: Simon and Schuster.
- Young, T., and M. Guy. 2008. “The Moon’s Phases and the Self Shadow.” *Science and Children* 46 (1): 30.

698

699 Grade 6 Instructional segment 2: Atmosphere: Cycles of Energy

Instructional segment 2: Atmosphere: Cycles of Energy
Guiding Questions: • Why is it cold at the North Pole? (Or, why does Santa wear a big red suit?) • What causes California's summers to be hot and dry? What causes the changes between summer and winter? • Why is there more rain in northern California than Southern California? • What effect do humans have on Earth's climate?
Highlighted Scientific and Engineering Practices: • **Ask questions** • **Develop and use models**
Highlighted Cross-cutting concepts: • ***Patterns*** • ***Energy and matter flow*** • ***Cause and effect***
Students who demonstrate understanding can: **MS-ESS1-1. Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons.** [Clarification Statement: Examples of models can be physical, graphical, or conceptual.] (Continued from instructional segment 1) **MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates.** [Clarification Statement: Emphasis is on how patterns vary by latitude, altitude, and geographic land distribution. Emphasis of atmospheric circulation is on the sunlight-driven latitudinal banding, the Coriolis effect, and resulting prevailing winds; emphasis of ocean circulation is on the transfer of heat by the global ocean convection cycle, which is constrained by the Coriolis effect and the outlines of continents. Examples of models can be diagrams, maps and globes, or digital representations.] [Assessment Boundary: Assessment does not include the dynamics of the Coriolis effect.] **MS-ESS3-4. Construct an argument supported by evidence for how increases in**

human population and per-capita consumption of natural resources impact Earth's systems. [Clarification Statement: Examples of evidence include grade-appropriate databases on human populations and the rates of consumption of food and natural resources (such as freshwater, mineral, and energy). Examples of impacts can include changes to the appearance, composition, and structure of Earth's systems as well as the rates at which they change. The consequences of increases in human populations and consumption of natural resources are described by science, but science does not make the decisions for the actions society takes.]

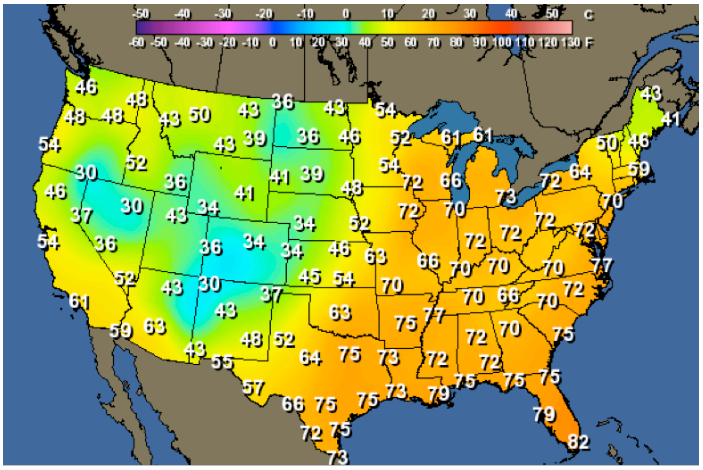
MS-ESS3-5. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century. [Clarification Statement: Examples of factors include human activities (such as fossil fuel combustion, cement production, and agricultural activity) and natural processes (such as changes in incoming solar radiation or volcanic activity). Examples of evidence can include tables, graphs, and maps of global and regional temperatures, atmospheric levels of gases such as carbon dioxide and methane, and the rates of human activities. Emphasis is on the major role that human activities play in causing the rise in global temperatures.]

Significant Connections to California's Environmental Principles and Concepts:

Principle III. Natural systems proceed through cycles that humans depend upon, benefit from and can alter.

Principle IV. The exchange of matter between natural systems and human societies affects the long term functioning of both.

Background and instructional Suggestions



Temperature in F 6:30 am Oct 8

Figure 2. A snapshot of morning temperatures across the USA reveals the importance of sunlight in affecting the temperature near Earth's surface. Image Credit:

During middle school, students identify some basic ***patterns*** in Earth's climate and **develop a model** of the factors that ***cause*** those patterns. The model is simple and related primarily to one part of Earth's ***energy*** balance, the input from the Sun. They extend this model in high school, so it is important to build this basic foundation (*HS-ESS2-4*).

Their **model** begins at the simplest level with recognizing that the more intense the solar input, the warmer temperatures are on Earth. Students can discover this pattern by looking at a map of temperature in the early morning across the USA. Look at **Figure 2** and draw a line dividing the country in half. What explains this simple ***pattern***? The Sun has risen already across the east coast and has warmed it up. Students can also identify other trends such as the warming towards the southern half of the country and the behavior of California that appears warmer than its neighbors despite the fact that the Sun has not yet risen.

Average temperature versus latitude

Figure 2 is just a snapshot in time that quickly changes, but there are also trends that last much longer. Should you bring beach clothes or a warm coat on a trip to Antarctica? How about San Diego, where it has only snowed 5 times there in the last 125 years? How about Lake Tahoe, which typically receives more than 10 feet of snow in the winter but is a popular recreation area for swimmers and boaters every summer. Different cities tend to have predictable ***patterns*** in their weather that depend on the city's location and the time of year (their 'climate'). Students **investigate** these patterns across the globe by **obtaining temperature information** from web sources[5] or from a simplified version for teaching[6].

Common Core Connection

Students plot climatograms showing the average temperature for each month (*CA CCSSM 6.SP.4*). They calculate the average temperature of each city over the entire year, as well as its spread throughout the year (*CA CCSSM 6.SP.2*, *CA CCSSM .6.SP.3*).

Constructing a dot-plot with average annual temperature versus latitude and temperature spread versus latitude reveals an important ***pattern***. Students probably already knew that it was cold at the North Pole, but why is there such a large temperature range at the poles and not at the equator? Within 20 degrees of the equator and 20 degrees of the poles, latitude doesn't have a major impact on climate and cities share fairly similar climates to one another. In between these sections of the Earth, climate varies greatly with latitude. Students should start **asking questions** about the cause of these differences.

Like the temperature map in **Figure 2**, these long-term temperature differences relate to the difference in energy received from the Sun. How can the equator appear to receive more energy than the either of the poles despite the fact that they all receive their energy from the same Sun? The key is that the Earth is a sphere. Sunlight arrives at Earth as parallel rays, but hits the surface at nearly a 90° angle near the equator and at flatter/smaller angles near the poles because of Earth's round shape. The light spreads out over a larger area near the poles, meaning that each square foot patch of the surface receives a smaller ***proportion*** of the energy coming from the Sun than that same patch does at the equator (**Figure 3**), which causes the sunlight on that patch to be less intense. When the sun shines down at a 90° angle, a patch of land receives

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[5] NOAA, *Global Historical Climatology Network-Monthly (GHCN-M)*: http://www.ncdc.noaa.gov/ghcnm/v3.php

[6] My version is at http://zadok.org/climate, but there is probably something better for middle school.

twice the energy compared to a 30° angle, so this effect has a big impact on the temperature. So even though the entire Earth receives energy from the same Sun, each section receives a different portion of the Sun's rays, depending on its latitude (**Figure 4**).

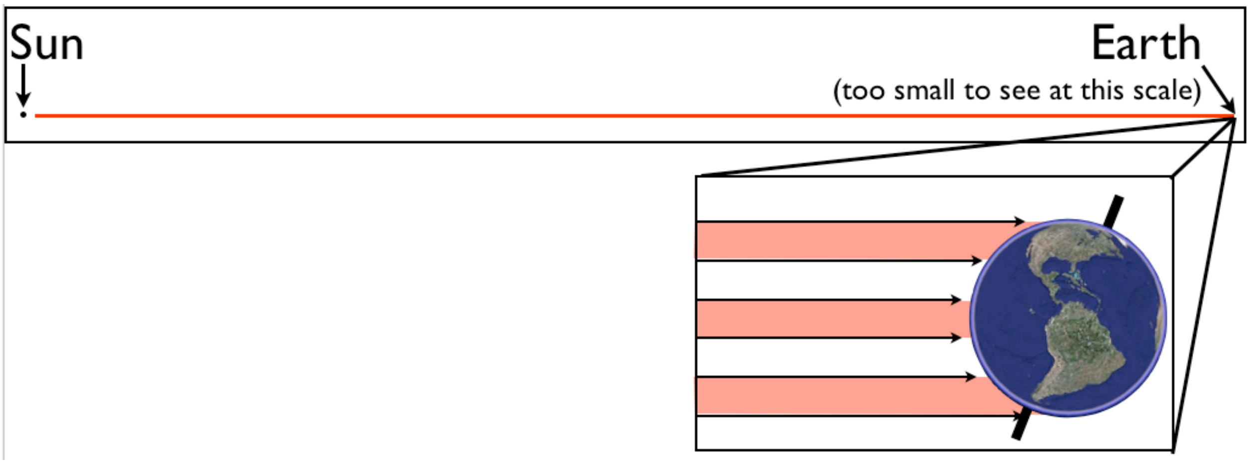

Figure 3. A scale illustration of the Earth-Sun system (top). The Sun is 5 pixels wide and the Earth is 1075 pixels away, but is only 0.05 pixels wide, which is too small to display. At this scale, it is easier to recognize that rays of sunlight arrive at Earth as parallel rays at all latitudes (bottom). Image Credit: (CC-BY-NC-SA) M. d'Alessio.

Students perform an **investigation** of the relationship between light intensity and angle by shining a flashlight at a piece of paper at different angles while keeping the distance between the light and the paper constant (NASA 2008). Students can directly observe how the patch of light gets dimmer when it strikes the page at a low angle and spreads out over a large area. While a piece of paper is flat, students simulate the parallel rays of sunlight arriving at Earth by shining their flashlight on a round ball and observing how the patch of light is small and intense near the equator but spread out near the poles.

Engineering connection: Solar array design

This concept has important engineering applications for solar energy. California hosts several of the world's largest arrays of solar panels in the world. When people place solar

Engineering Connection

panels on their roofs, the angle of the panels is usually fixed by the angle of the roof. To maximize efficiency at large solar power arrays, the motors constantly turn the panels so that they face the Sun at an angle as close to 90° as possible to get the maximum energy output. Students can experience this effect in a classroom with a small solar panel hooked up to an electric motor. As they rotate the solar panel to change the angle of sunlight, the energy output ***changes*** so that the motor turns at a different speed (New York State Energy Research and Development Authority 2015). Students could engage in an engineering challenge to design a rotating base for solar panels that has the necessary range of movement (both tilting and swiveling) and uses low cost materials (*MS-ETS1-1*, *MS-ETS1-2*).

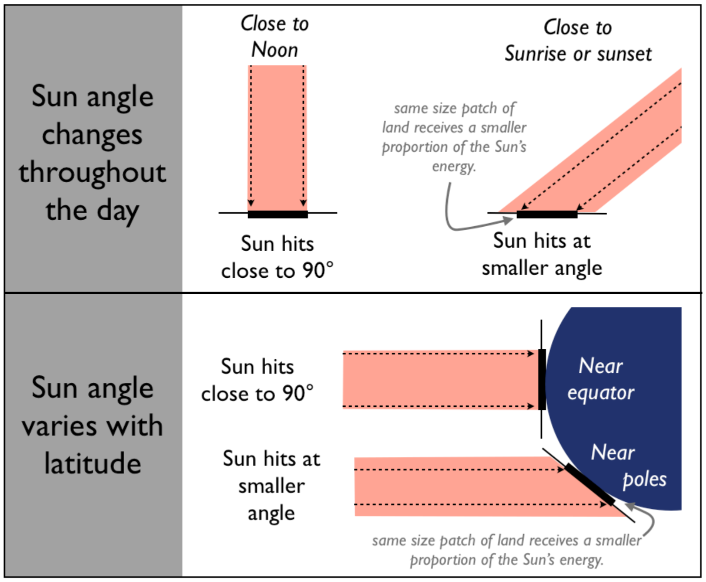

Figure 4. Effect of the angle of the Sun's rays on area of the Earth's surface it illuminates. At angles smaller than 90°, the energy is spread out over a larger area. The effect is important as the sun moves across the sky during one day (top) and at different latitudes across the planet (bottom). Image Credit: (CC-BY-NC-SA) M. d'Alessio.

Uneven Heating and the Earth's 'Circulation System'

The uneven heating between the equator and the poles is the root ***cause*** of all earth's ocean and wind currents. They carry hot material (water in the oceans and air in the atmosphere) from the equator towards the poles in a large-***scale*** convection current. Convection is a ***cycling of matter*** driven by the ***flow of energy*** (connects to *MS-ESS2-*

1, though assessment of that PE focuses largely on the solid Earth). As hot material moves poleward, colder material moves towards the equator. Without currents, regional temperatures would be extreme — super hot at the equator and frigid toward the poles—and much less of Earth's land would be habitable. Sunlight heats Earth's surface, which in turn heats the atmosphere. At the global scale, wind currents are dominated by three different directions of motion: 1) hot material rising vertically upward and cold material sinking vertically downward due to convection; 2) hot material from the equator moving northward towards the poles and cold material moving southward towards the equator due to convection; and 3) east-west apparent motion of material driven by Earth's rotation. Ocean currents undergo similar motions modified by collisions with the coastlines that disrupt these ideal motions. While wind directions also change when they rise up over or flow around mountains, the difference is less than in the ocean where water must completely change direction.

Under the 1998 California standards, students discussed convection in both 5th and 6th grade, but under the *CA NGSS* this instructional segment is likely the first time students encounter the concept of convection. They will therefore need hands-on experience with the process in order to develop mental **models** of convection. These models begin with simple visualizations of convection using miso soup, rheoscopic fluid, or food coloring with water that allow students to recognize some general ***patterns*** of motion. They can then conduct more detailed **investigations** mapping out the motion of individual particles to provide evidence that supports the **argument** that uneven heating ***causes*** these patterns[7]. Students should be able to apply their model of convection to predicting the direction wind or water will move when exposed to uneven heating at the regional ***scale*** (a part of *MS-ESS2-6*). In India, changes in the heating differential between winter and summer cause the prevailing wind direction to reverse direction almost completely, creating their famous monsoons. Along the California coastline, we see this effect every day as the wind switches direction from morning to evening as the temperature difference between land and water switches direction.

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[7] UCAR, Atmospheric Processes-Convection: https://www.ucar.edu/learn/1_1_2_7t.htm

Understanding how convection works at the global ***scale*** helps explain many ***patterns*** in wind and precipitation. The strong temperature difference between equator and poles sets up convection, but as air masses move northward, some of their ***energy flows*** to their surroundings through cooling and drag. As a result, air from the equator does not make it all the way to the poles before it sinks back to the surface. Instead, our present-day atmosphere involves three major convection cells divided into latitudinal bands (**Figure 5**). Regions at the boundary between these convection cells tend to be areas with more dramatic weather: where both convection cells have air rising, thunderstorms are generated while the convergence between air masses at the upper mid-latitudes typically gives rise to rainier weather patterns.

Climate ***patterns*** are not permanent, and ***changes*** to the energy balance on the planet can ***cause changes*** to convection. The convection cells migrate with the seasons as well as local temperature variations. We see these changes as migrations of the jet streams, high velocity winds that race in the upper atmosphere along the boundary between convection cells. In the winter time, the convection cell boundary moves towards the south, bringing California its rainy winters that dry up in the summer as the convection boundary migrates back northward. Southern Europe is located at a similar latitude, so it has a similar pattern of weather, which is why our climate is often referred to as a “Mediterranean climate.” Students may not realize that large portions of the planet actually get the majority of their rain in the summer and that our unique climate is used to our unique position on the globe.

In addition to seasonal ***changes*** to the energy balance on the planet, ***changes*** at longer ***timescales*** can also occur. Computer simulations show that in periods of geologic history when there was a smaller temperature differential between the equator and poles, Earth may have had one large convection cell for each hemisphere spanning the entire region from equator to pole. Future climate changes may again disrupt wind and ocean currents.

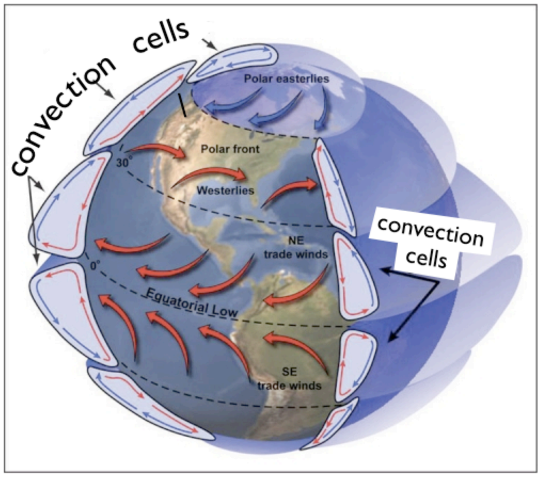

Figure 5. Latitudinal bands in earth's atmospheric circulation. (NC State University 2013)

Additional background for teachers on Coriolis effects

If simple convection were the only process controlling air movements, all wind would flow in the north-south direction, but we know that is not true. Earth's rotation modifies this path. The assessment boundary for *MS-ESS2-6* states that "Assessment does not include the dynamics of the Coriolis effect," so the exact details of this process are not essential for students but it may be desired by curious teachers and students. Air rotates around the Earth just like the planet overall. Material races around the equator at 1,700 km/hr to complete one full rotation in 24 hours, but it hardly needs to move at all near the poles. As a parcel of air travels from the fast moving equator towards the poles, it is moving faster in the direction of Earth's rotation than the ground underneath it. From our perspective on the surface, it appears to be veering off in the direction of Earth's rotation. Air moving from the poles towards the equator is moving slower than the ground underneath it, so it gets 'left behind' and appears to make a turn away from the rotation direction. Together, these deflections set up predictable bands of wind direction near the surface, and gives rise to the jet streams in the upper atmosphere.

Angle of Sunlight and Seasons

The angle of the Sun's rays is also important for determining the variations in temperature during Earth's seasons. Students combine their understanding of the effect of sunlight angle on energy input from this instructional segment with the orbital motions in the previous instructional segment to create a **model** that explains the reason for Earth's repeating ***pattern*** of seasons (*MS-ESS1-1*). Students can make these connections using a physical model where their own body represents the motion of the planet[8]. They tilt their body towards or away from the Sun at the same 23.5° tilt as the Earth and move around Earth's orbit, making sure that their tilt axis always points towards the North star. As they move from one side of the Sun to the other, they see how the angle of the Sun's rays ***changes*** in the different hemispheres: in the northern hemisphere summer, the tilt brings the angle of the Sun's rays closer to 90° while it makes the angle smaller in the southern hemisphere. Computer simulations allow students another way to visualize these changes[9].

Learning a scientifically accurate model for the seasons is often impeded by students' incoming preconceptions (documented vividly in the short documentary *Private Universe*[10] and in review articles[11]). Most notably, students often incorrectly believe that the Earth is closer to the Sun in summer and farther in winter. In this example course sequence, seasons are deliberately placed in a separate instructional segment from the discussion of orbits in order to increase the association between seasons and Sun angle instead of reinforcing an incorrect connection between seasons and orbital distance. Nonetheless, many students will still harbor this preconception and it must be addressed. Interactive 3-D simulations have been shown to help students

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[8] Space Science Institute, Kinesthetic Astronomy. http://www.spacescience.org/education/extra/kinesthetic_astronomy/

[9] NOAA, Seasons and Ecliptic Simulator, https://www.climate.gov/teaching/resources/seasons-and-ecliptic-simulator

[10] Harvard-Smithsonian Center for Astrophysics, Private Universe. http://www.learner.org/resources/series28.html?pop=yes&pid=9

[11] http://dx.doi.org/10.3847/AER2010035

confront this preconception[12]. In these virtual worlds, students view the Sun-Moon-Earth ***system*** from various viewpoints and control different aspects, including rotation and revolution rates, and inclination of Earth's spin axis. The story of seasons is mostly a story of light and energy absorption. Emphasis should be placed on the intensity and duration that sunlight shines on a particular patch of Earth's surface. Because Earth's tilt causes the Sun to appear to travel across the sky along a different path during summer versus winter, the Sun shines for longer days (causing longer duration sunlight) and from higher angles in the sky (causing more sunlight appear more intense in a given patch of the surface). Together, these give rise to warmer summers and cooler winters.

Climate change

Weather ***changes*** on many different ***timescales***. There are trends and ***patterns*** that occur over hours, days, seasons, years, decades, and millennia. Shorter term variations are discussed in the next instructional segment. Scientists typically use the word 'climate' to describe patterns of weather that change over longer timescales. Many textbooks overemphasize the difference between the terms weather and climate; they are not different things but instead describe patterns and changes in atmospheric conditions over different timescales. The exact timescale that separates 'weather patterns' from 'climate patterns' is not universally agreed upon, but climate typically includes patterns that persist for decades or longer. Often, climate not only refers to the average conditions for a given location, but also includes a sense of the range of variation throughout the seasons and from year-to-year. Some climate changes may involve relatively small shifts to the average conditions, but substantially more frequent extreme weather (i.e., more severe droughts balanced by more extreme flooding or frequent heat waves balanced by frequent cold snaps).

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[12] Something similar to this simulation is located here: http://astro.unl.edu/naap/motion1/animations/seasons_ecliptic.html, but it is described in Bakas and Mikropoulos 2003

Common Core Connection

Because temperature is a tangible topic and students have experience with its variation, climate data make an excellent way to engage students in 6th grade mathematics standards about statistics (*CA CCSSM.6.SP.A*).

Changes at each ***timescale*** are driven by different ***causes***. Some climate changes in Earth's history were rapid shifts (caused by events, such as volcanic eruptions and meteoric impacts that suddenly put a large amount of particulate matter into the atmosphere or by abrupt changes in ocean currents). Other climate changes were gradual and longer term—due, for example, to solar output variations, shifts in the tilt of Earth's axis, or atmospheric change due to the rise of plants and other life forms that modified the atmosphere via photosynthesis. Scientists can infer these changes from geological evidence. Students can **analyze data** from these scientific observations to see how each process can correlate with observed changes in climate. Excellent data sets from tree rings and cherry blossoms exist showing how changes in sunspots and volcanic eruptions were recorded as changes in plant growth over the last 1,000 years[13].

Students begin to **analyze data** showing the temperature history over the last century (**Figure 6**). The focus in middle school is on **asking questions** about the ***patterns*** they see (*MS-ESS3-5*). In high school, students will build a **model** that can help explain the mechanisms causing the ***changes*** they see. While graphs like **Figure 6** are simple enough for students to interpret, scientists also use more sophisticated interactive displays of data that depict how temperatures have changed in space and time. More advanced visualizations allow students to zoom into areas of interest (such as regions within California) and watch the time progression[14]. As students see the data depicted in new ways, they should be able to ask more detailed questions. For example, the right panel of **Figure 6** shows that the northern hemisphere has warmed more than

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[13] National Center for Atmospheric Research, Investigating Climate Past: The Little Ice Age Case Study: http://eo.ucar.edu/educators/ClimateDiscovery/LIA.htm

[14] California Energy Commission, Cal-Adapt: http://cal-adapt.org/tools/

the southern hemisphere. Why? The eastern part of South America warmed more than the west. Is that due to deforestation of the Amazon, or does it involve more complex interactions? The lowest temperatures are shortly after 1900. What caused that? Did it affect the whole planet equally? These are the types of **questions** we want our students to start asking even though they won't have the tools to answer them yet in sixth grade.

The data also come alive when students **obtain information** about the ***effect*** temperature ***changes*** have on sea-level, glaciers, or storm intensity. There are a number of government reports summarizing these changes (EPA Climate Change Indicators[15], National Climate Assessment[16] or NASA's Climate Effects web portal[17]). Students can research one aspect and prepare a summary product for the class that **communicates** their findings.

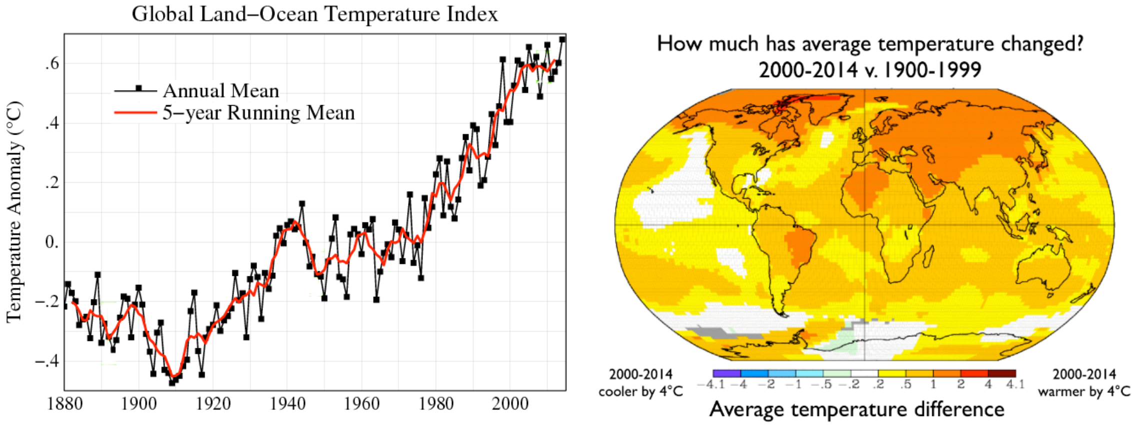

Figure 6. Temperature changes over time depicted as a graph of average annual temperatures for the entire globe since 1880 (left) and a map showing changes at different locations, comparing the average from the first portion of the 21st century to the 20th century (right). The 21st century is warmer than the 19th and 20th centuries. (NASA 2015)

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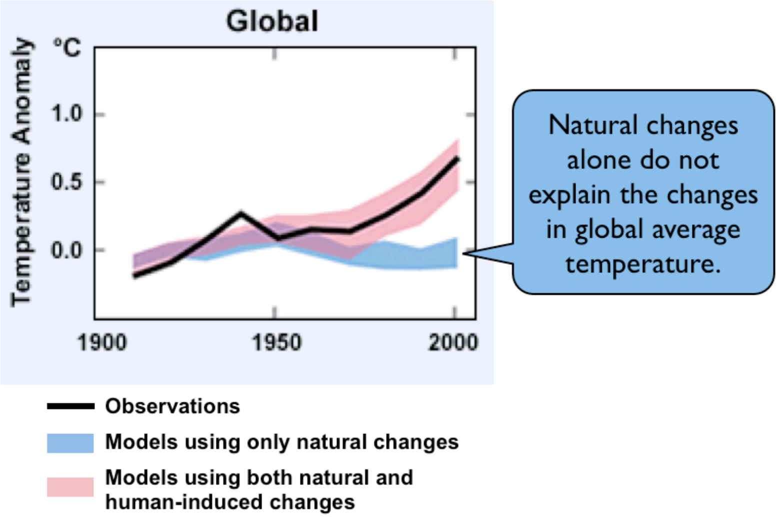
[15] EPA, Climate Change Indicators: http://www.epa.gov/climatechange/science/indicators/

[16] National Climate Assessment: http://nca2014.globalchange.gov/report#section-1946

[17] http://climate.nasa.gov/effects/

There exist natural factors that can ***cause*** climate ***changes*** over human ***timescales*** (tens or hundreds of years), including variations in the Sun's energy output, ocean circulation ***patterns***, atmospheric composition, and volcanic activity (see ESS3.D). When ocean currents change their flow ***patterns***, such as during El Niño Southern Oscillation conditions, some global regions become warmer or wetter and others become colder or drier. When scientists make computer simulations that include only these natural ***changes***, they cannot match the temperature changes from the last century (**Figure 7**). But there are also changes that are caused by human activity (EP&C Principles III & IV). Many aspects of modern society result in the release of carbon dioxide and other greenhouse gases. These include automobiles, power plants or factories that use coal, oil, or gas as an energy source, cement production for buildings and roads, burning forest and agricultural land, and even the raising of livestock whose digestive processes emit methane. Greenhouse gases increase the capacity of Earth to retain energy, so changes in these gases cause changes in Earth's average temperature. Changes in surface or atmospheric reflectivity change the amount of energy from the Sun that enters the planetary system. Icy surfaces, clouds, aerosols, and larger particles in the atmosphere, such as from volcanic ash, reflect sunlight and thereby decrease the amount of solar energy that can enter the weather/ climate system. Many surfaces that humans construct (e.g., roads, most buildings, agricultural fields versus natural forests) absorb sunlight and thus increase the ***energy*** in the ***system***. As students **analyze data** about greenhouse gas concentrations in the atmosphere, they observe a very similar ***pattern*** to the change in temperature (**Figure 8**). In fact, computer models of climate show that human activities are an important part of the ***cause*** of global temperature changes (**Figure 7**).

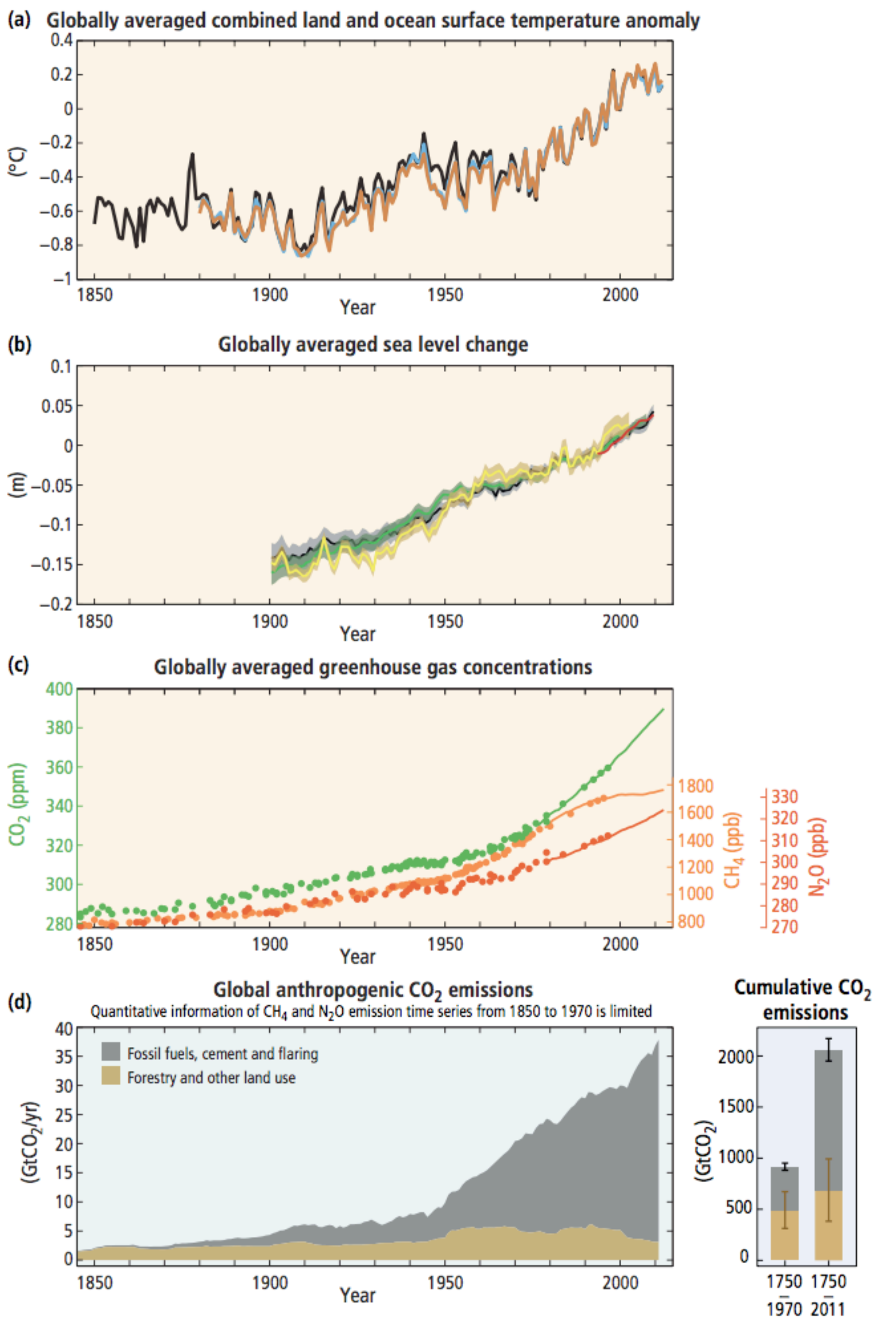


Natural changes alone do not explain the changes in global average temperature.

Figure 7. Outputs of different computer models of global climate compared to observations. The colored bands are thick because they represent hundreds of different models created by many different researchers using different assumptions. While the models have slight variations in their output, only models that include human-induced changes can explain the observed temperature record.

Common Core Connection

Global average temperature rises as humans emit more greenhouse gases. This rate of emission depends on two key variables: population growth, and ***energy*** consumed per person. Students must **construct an argument from evidence** that connects these population and energy use ideas to a significant impact on Earth's systems (*MS-ESS3-4*). To gather evidence for their argument, students **obtain information** from online resources that list population and energy consumption ***patterns***. Students will use **mathematical thinking** to create meaningful comparisons between the energy use in different states and countries. For example, energy use per person is an example of an 'instructional segment rate' from ratio thinking in mathematics (*CA CCSSM 6.RP.2*). People in the US use more than twice as much energy per person than the average European country (U.S. Energy Information Administration 2015a), probably because our homes are bigger and spaced further apart. Californians, on average, use less energy per person than nearly every other state in the US (U.S. Energy Information Administration 2015b), partly due to our mild climate and partly due to effective energy efficiency programs. Despite this fact, the average Californian still uses more than 10 times more energy than the average person in the continent of Africa. These comparisons are examples of ratios and ratio language (*CA CCSSM 6.RP.1*). Many developing countries around the world have growing populations and are rapidly changing their lifestyles to include more energy intensive tools. They will start consuming energy at rates more like California or even the US average, which could have a huge impact on global climate and global emissions. Computer **models** that forecast ***changes*** in global climate rely on accurate estimates about energy consumption in the future, and in high school students will use computer simulations to explore the effects of these assumptions (*HS-ESS3-5*).



(a) Globally averaged combined land and ocean surface temperature anomaly

(b) Globally averaged sea level change

(c) Globally averaged greenhouse gas concentrations

(d) Global anthropogenic CO_2 emissions

Quantitative information of CH_4 and N_2O emission time series from 1850 to 1970 is limited

Cumulative CO_2 emissions

Figure 8. Graphs with similar trends and patterns illustrate global warming causes and effects. (Intergovernmental Panel on Climate Change 2014)

Grade 6 Instructional segment 3: Atmosphere/Hydrosphere: Cycles of Matter

Instructional segment 3: Atmosphere/Hydrosphere: Cycles of Matter

Guiding Questions:

- How do we predict tomorrow's weather?
- How do the atmosphere and hydrosphere interact to control our valuable water resources?

Highlighted Scientific and Engineering Practices:

- Developing and using models
- Analyzing and interpreting data
- Planning and carrying out investigations

Highlighted Cross-cutting concepts:

- *Energy and matter: Flows, cycles, and conservation*
- *Patterns*
- *Cause and effect*

Students who demonstrate understanding can:

MS-ESS2-5. Collect data to provide evidence for how the motions and complex interactions of air masses results in changes in weather conditions. [Clarification Statement: Emphasis is on how air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time, and how sudden changes in weather can result when different air masses collide. Emphasis is on how weather can be predicted within probabilistic ranges. Examples of data can be provided to students (such as weather maps, diagrams, and visualizations) or obtained through laboratory experiments (such as with condensation).] [Assessment Boundary: Assessment does not include recalling the names of cloud types or weather symbols used on weather maps or the reported diagrams from weather stations.]

MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates. [Clarification Statement: Emphasis is on how patterns vary by latitude, altitude, and geographic land distribution. Emphasis of atmospheric circulation is on the sunlight-driven latitudinal banding, the Coriolis effect, and resulting prevailing winds; emphasis of ocean circulation is on the transfer of heat by the global ocean convection cycle, which is constrained by the Coriolis effect and the outlines of continents. Examples of models can be diagrams, maps and globes, or digital representations.] [Assessment Boundary: Assessment does not include the dynamics of the Coriolis effect.]

MS-ESS3-2. Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects. [Clarification Statement: Emphasis is on how some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions, but others, such as earthquakes, occur suddenly and with no notice, and thus are not yet predictable. Examples of natural hazards can be taken from interior processes (such as earthquakes and volcanic eruptions), surface processes (such as mass wasting and tsunamis), or severe weather events (such as hurricanes, tornadoes, and floods). Examples of data can include the locations, magnitudes, and frequencies of the natural hazards. Examples of technologies can be global (such as satellite systems to monitor hurricanes or forest fires) or local (such as building basements in tornado-prone regions or reservoirs to mitigate droughts).]

MS-ESS2-1. Develop a model to describe the cycling of Earth’s materials and the flow of energy that drives this process. [Clarification Statement: Emphasis is on the processes of melting, crystallization, weathering, deformation, and sedimentation, which act together to form minerals and rocks through the cycling of Earth’s materials.] [Assessment Boundary: Assessment does not include the identification and naming of minerals.]

MS-ESS2-4. Develop a model to describe the cycling of water through Earth’s systems driven by energy from the Sun and the force of gravity. [Clarification Statement: Emphasis is on the ways water changes its state as it moves through the multiple pathways of the hydrologic cycle. Examples of models can be conceptual or physical.] [Assessment Boundary: A quantitative understanding of the latent heats of vaporization and fusion is not assessed.]

MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth’s systems. [Clarification Statement: Examples of evidence include grade-appropriate databases on human populations and the rates of consumption of food and natural resources (such as freshwater, mineral, and energy). Examples of impacts can include changes to the appearance, composition, and structure of Earth’s systems as well as the rates at which they change. The consequences of increases in human populations and consumption of natural resources are described by science, but science does not make the decisions for the actions society takes.]

Other necessary DCIs
PS3.B: Conservation of Energy and Energy Transfer
PS4.B: Electromagnetic radiation

Significant Connections to California's Environmental Principles and Concepts:
Principle I. The continuation and health of individual human lives and of human communities and societies depend on the health of the natural systems that provide essential goods and ecosystem services.
Principle III. Natural systems proceed through cycles that humans depend upon, benefit from and can alter.
Principle IV. The exchange of matter between natural systems and human societies affects the long term functioning of both.

Background and instructional Suggestions

California is known for its sunshine more often than its rain and snow, but it relies on both of these to support its extremely productive agricultural sector and supply water to its growing population (*EP&C I*). The previous instructional segment focused on ***energy flows*** and briefly mentioned the ***flow of matter*** that enabled some of the energy transfer. This instructional segment looks at the same processes from the perspective of the ***cycling of matter*** in both the atmosphere and the hydrosphere (*EP&C III*).

The instructional segment on weather can be structured around the goal of having each student create a weather forecast for their community. Classroom instruction focuses on providing students the skills and background they need to complete that task. The forecast theme allows students to explicitly name the observable variables that describe their experience with weather: temperature, wind, humidity, and precipitation, and air pressure. Even though the last variable, air pressure, is crucial to understanding weather ***changes***, an effective inquiry-based approach does not introduce it as a key variable at the beginning. After all, people do not directly sense or feel changes in air pressure. Teachers focus on the observable quantities and then encourage students to **ask questions** about what causes them to change.

Students then **analyze data**, searching for ***patterns*** in the observable weather variables that give clues about the ***causes*** of the ***changes*** (*MS-ESS2-5*). Students can examine detailed maps of air pressure and wind patterns to discover that air moves from high pressure to low pressure[18]. Understanding why this is true requires some understanding of gases as particles. In 5th grade, students defined matter as particles that are too small to see (*5-PS1-1*). In the discipline specific course sequence, they have not yet **developed a model** of how those particles behave (it comes in 8th grade, *MS-PS1- 4*), so a partial model will need to be developed for this discussion. This model simply defines high pressure as having lots of particles of air together in one place, all moving and pushing against one another like people on a crowded dance floor. Lower pressure regions are areas that have fewer particles packed together with more empty space between them. Air particles from the crowded regions will get bumped and pushed into those empty spaces such that there is an overall flow from high pressure to low pressure.

Students combine this **model** with their model of global convection from the previous unit to create an even richer understanding of the movement of air and water on Earth (*MS-ESS2-6*). The problem is best illustrated at a small ***scale*** along coastlines where land masses are adjacent to water. Students conduct an **investigation** into the thermal properties of land versus water to see how they heat and cool at different rates, setting up temperature differentials. This uneven heating ***causes*** convection (the movement of air) along coastlines just like it did on the global ***scale*** with the temperature differential between the equator and the poles. As air heats up, the particles spread out, with some of the warmer air rising upwards. The area where air rises up is now lower pressure than its surroundings, so air begins to move from areas

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[18] American Meteorological Society, The Data Stream: http://www.ametsoc.org/amsedu/dstreme/

where the pressure is higher (typically colder areas). Wind (the movement of air) results from this convection cycle.

The clarification statement for *MS-ESS2-5* indicates that students will not be assessed on weather map symbols. This is largely a reaction to the fact that these symbols are no longer necessary for illustrating weather ***patterns*** in the digital age. For example, real-time wind patterns are indicated with animations of the flow of individual particles[19] or with familiar rainbow color scales[20]. These visualization tools allow teachers to spend more time helping students recognize and explain patterns with less time devoted to memorizing symbols.

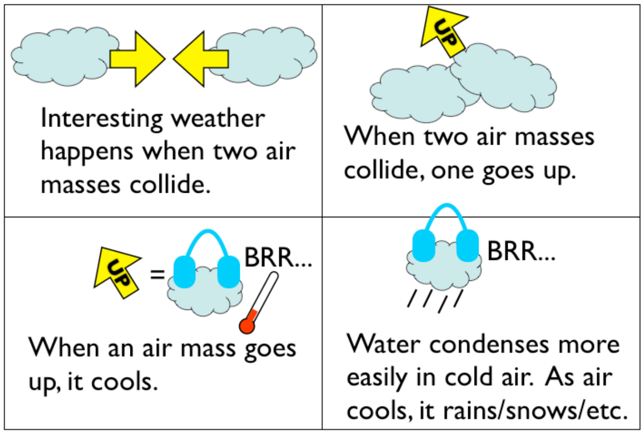

Figure 9. Important components of a model of weather that describes the interaction of air masses.

Using animations of real-time observations (such as satellite data from visible light that reveals clouds and other wavelengths that reveal water vapor[21]), students collect data about the movement of large air masses, noticing that the most intense

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[19] Wind Map: http://hint.fm/wind/

[20] Earth: http://earth.nullschool.net/#current/wind/surface/level/

[21] NOAA, Geostational Satellite Server: GOES Western U.S. Water Vapor: http://www.goes.noaa.gov/browsw3.html

precipitation and weather events occur where air masses collide (*MS-ESS2-5*). These observations form the **evidence** that can be used to construct a complete **explanation** or a **model** of the relationship between air masses and changing weather conditions. The conceptual model in **Figure 9** shows that these explanations require further investigation into condensation and the movement of water within Earth's systems.

For a vignette related to weather, please see grade six of the Preferred Integrated Model.

Water Cycle

At this point in Earth's history, very little water leaves the planet or arrives from space. We simply need to track the movement of the matter that is already here. The water cycle is therefore an example of a ***cycle of matter*** within a relatively closed ***system***. In 5th grade, students created graphs to illustrate where water is located on Earth (*5-ESS2-2*) and they developed a **model** for the cycling of matter within the biosphere (5-LS2-1). In 6th grade, they will extend their **model** to include the exchange of water between all of Earth's ***systems***, which should enable them to explain the distribution of water they observed in 5th grade.

Students hold many preconceptions about the way water is cycled through Earth's systems (Ben-zvi-Assarf and Orion 2005). While they may be able to list the locations where water can be found, they often are lacking a **model** for the interconnectedness between these ***systems*** (i.e., water that is in the ground can flow into rivers, oceans, or reach the surface at springs), or a sense for the dynamic movement of water within each system (i.e., surface water doesn't just sit there waiting to evaporate, but flows constantly down towards the oceans). Teachers can help illustrate the dynamic interconnectedness of the water cycle through a simple kinesthetic game. Students each play the role of a water molecule and will move around the room through different stations that represent places where water is found on Earth (ocean, lake, animal, plant, groundwater, atmosphere, ice cap, etc.). At each station, they roll a dice and read from a table about the process that they will undergo so that they can move from one station to another (i.e., evaporation, infiltration into the ground, flow downhill, come to the surface at a mountain spring, etc.). In essence, they become a physical **model** for all the processes in the water cycle (*MS-ESS2-4*). The model helps illustrate a number of concepts: 1) each of the reservoirs of groundwater are interconnected; 2) water is constantly moving and flowing within each system and between systems; 3) water is in different states (solid, liquid, and gas) in different reservoirs, and ***changes*** in state (evaporation, condensation) are one key way that water can move between different reservoirs; 4) there is no start, end, or single path through the water cycle; and 5) changes in one part of the water cycle will have a major impact on other parts of the system (e.g., if ice caps melt, sea level will rise; if the climate warms and causes more evaporation, that will lead to more precipitation, which will lead to more runoff).

A model of the water cycle that only describes the ***cycling of matter*** does not completely fulfill *MS-ESS2-4*, which requires students to explain how ***energy*** exchanged via sunlight and gravity drives much of the movement. Additional **investigations** into several of the process that cause movement of water through the water cycle will help students understand these processes well enough to integrate them into their **model**.

Energy from sunlight has an ***effect*** on the water cycle because the increase in thermal energy that it ***causes*** can in turn ***cause*** phase ***changes***. Students conduct **investigations** into evaporation and condensation to experience how they enable the cycling of water and how they relate to ***energy flow.*** They recognize the ***pattern*** that when water absorbs energy, it heats up and evaporates more readily. As water cools, it tends to condense. Because they lack a detailed model of matter and state changes are not introduced until 8th grade (*MS-PS1-4*), many students come away from these activities believing the incorrect idea that water is the only material that can exist in all three states of matter (after all, we only conduct this experiment with water and not other materials). This preconception gets reinforced when students hear the true statement that water is the only material that exists in all three states at the range of natural temperatures on Earth (they seem to ignore the last part about natural temperatures on Earth).

The force of gravity also ***causes*** movement in the water cycle. Most students are able to explain the role of gravity in precipitation (“raindrops fall”) or surface water (“rivers flow downhill”), but often overlook the crucial role that gravity plays in infiltration of surface water into the groundwater, the flow of groundwater itself through tiny pores (illustrated as a saturated sponge drips water down out the bottom), and the flow of ice downhill in glaciers (easily illustrated by time-lapse videos of glacier movement). In order to emphasize these ***cause and effect*** relationships with gravity, students create skits of different processes within the water cycle where one student is assigned to play gravity or sunlight and must interact with other characters in the skit such as water molecules or grains of sand. Short dramatic performances have been shown to improve students’ conceptual understanding in science classes (Ødegaard 2003) and should support language development. Drama comes in many forms, but can be particularly well suited to **developing models** of ***systems*** by having individual characters play the role of components within the system while their words and actions portray the relationships between the components. The exchange of props between characters can be a physical **model** of ***cycles of matter***.

Engineering solutions to pollution moved by the water cycle

Moving water often carries pollutants along with it (*EP&C IV*), but understanding the water cycle allows people to design measures to stop the flow of pollution. One possible engineering challenge for students is to deal with the flow of water and pollutants in urban areas. As water runs along road surfaces, it picks up oil, grit, and other pollutants that could flow into storm drains and out into local waterways. During heavy rainstorms, those waterways can get overloaded and flood. Allowing a greater fraction of water to infiltrate into the ground can solve two problems because it reduces the amount of water on the surface that causes flooding and the soil filters out many harmful contaminants before they flow further. Students can be given the challenge of designing a system that divert waters into the ground and provides the maximum filtration of that water[22]. Students will have to define specific criteria to measure their success (*MS-ETS1-1*), brainstorm and compare different possibilities (*MS-ETS1-2*), test those possibilities (*MS-ETS1-3*), and make iterative improvements (*MS-ETS1-4*).

Human interaction with the Water Cycle

Because of the water cycle, Californians are able to obtain a steady supply of fresh water for drinking, irrigation, industrial, and agricultural uses (*California EP&C III*). Even in years with abundant precipitation, California still draws water from a total of seven nearby states in addition to its own supply (The Nature Conservancy of California 2012). Of the water extracted for human use ("developed water"), more than 75% of it goes to agriculture (California Department of Water Resources 2014) which helps California grow more food than any other state (USDA 2015). While water is part of all agriculture, some foods require more water to grow than others. If people choose to eat more water efficient foods, California can cut back on its per-capita consumption of water. Looking at data tables showing the water required for different food types, students can compare the water footprint of several different meals. They will find that a diet rich in meat products requires nearly twice as much water as a diet based on vegetables and other plant products. For example, the average beef burger takes 4 times more water to produce than the same number of calories from an average soy burger (Ercin, Aldaya, and Hoekstra 2012). The difference goes beyond water usage, but includes other resources such as the land area required to grow the food and ***energy*** resources to fertilize, transport, and process it. During their study of life science in 7th grade and high school, students will learn more about food pyramids and the concept of trophic levels that will help them understand why this should be the case. In brief, predators inherently require more total energy input from the ecosystem than their prey because of the energy used by the prey during its lifetime that is not preserved

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[22] Engineering is Everywhere, Don't Runoff: Engineering An Urban Landscape: http://www.eie.org/engineering-everywhere/curriculum-units/dont-runoff

within its biomass. Students can obtain global data about the relationship between urbanization, rising incomes, and large increases in the amount of meat consumed per person (expected to nearly double the levels from 1960 by the year 2030) (World Health Organization 2015). With more people in the world eating more meat, there is increasing pressure on water and other resources. Each family makes lifestyle choices about the food they eat, and students should be able to construct an **argument** that different lifestyle choices comes at the price of increased resource consumption (*MS-ESS3-4*).

Grade 6 Instructional segment 4: Geosphere: Surface Processes

Instructional segment 4: Geosphere: Surface Processes

Guiding Questions:

- How can we read layers of rock like the pages of a history book to reconstruct what happened during Earth's past?
- What is the relationship between the way rocks are built up (deposition) and the way rocks are broken down (erosion)?
- How does our understanding of erosion and deposition help us find valuable energy and water resources and make ourselves safer from landslides?

Highlighted Scientific and Engineering Practices:

- Constructing Explanations
- Performing investigations

Highlighted Cross-cutting concepts:

- *Structure and Function*

Students who demonstrate understanding can:

MS-ESS1-4. Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history. [Clarification Statement: Emphasis is on how analyses of rock formations and the fossils they contain are used to establish relative ages of major events in Earth's history. Examples of Earth's major events could range from being very recent (such as the last Ice Age or the earliest fossils of homo sapiens) to very old (such as the formation of Earth or the earliest evidence of life). Examples can include the formation of mountain chains and ocean basins, the evolution or extinction of particular living organisms, or significant volcanic eruptions.] [Assessment Boundary: Assessment does not include recalling the names of specific periods or epochs and events within them.]

MS-ESS2-1. Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process. [Clarification Statement: Emphasis is on the processes of melting, crystallization, weathering, deformation, and sedimentation, which act together to form minerals and rocks through the cycling of Earth's materials.] [Assessment Boundary: Assessment does not include the identification and naming of minerals.]

MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. [Clarification Statement: Emphasis is on how processes change

Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions), and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind. Emphasis is on geoscience processes that shape local geographic features, where appropriate.]

MS-ESS3-1. Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes. [Clarification Statement: Emphasis is on how these resources are limited and typically non-renewable, and how their distributions are significantly changing as a result of removal by humans. Examples of uneven distributions of resources as a result of past processes include but are not limited to petroleum (locations of the burial of organic marine sediments and subsequent geologic traps), metal ores (locations of past volcanic and hydrothermal activity associated with subduction zones), and soil (locations of active weathering and/or deposition of rock).]

MS-ESS3-2. Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects. [Clarification Statement: Emphasis is on how some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions, but others, such as earthquakes, occur suddenly and with no notice, and thus are not yet predictable. Examples of natural hazards can be taken from interior processes (such as earthquakes and volcanic eruptions), surface processes (such as mass wasting and tsunamis), or severe weather events (such as hurricanes, tornadoes, and floods). Examples of data can include the locations, magnitudes, and frequencies of the natural hazards. Examples of technologies can be global (such as satellite systems to monitor hurricanes or forest fires) or local (such as building basements in tornado-prone regions or reservoirs to mitigate droughts).]

Significant Connections to California's Environmental Principles and Concepts:

Principle I. The continuation and health of individual human lives and of human communities and societies depend on the health of the natural systems that provide essential goods and ecosystem services.

Principle III. Natural systems proceed through cycles that humans depend upon, benefit from and can alter.

Principle IV. The exchange of matter between natural systems and human societies affects the long term functioning of both.

Background and instructional Suggestions

Every rock records a story. Earth scientists look out on a landscape and **ask questions** about both the processes that are actively shaping it today and the specific sequence of events in the past that led up to the present-day. Scientists **plan and conduct investigations** to answer those questions, but investigations in Earth and space science cannot always take the same experimental form with the testing of hypotheses as they might in analytical chemistry or experimental physics. Many Earth processes take millions of years and cover thousands of miles of area, time and distance ***scales*** that are too slow and too large to reproduce in a lab. Geologists often refer to the Earth as their 'natural laboratory', but they are only permitted to look at the final result of its ancient experiments, or Earth's present-day landscape. Investigations in Earth science often begin with careful observations of what the Earth looks like today and then try to reproduce similar features in small-scale laboratory experiments or computer simulations.

Students can develop this Earth science mindset when walking around their own schoolyard and making observations about the familiar processes that led to its present-day state[23]. For example, students can probably picture a brick wall being built layer-by-layer, or that concrete starts off as grains of sand, gets mixed with cement, and then hardens into solid ground. Not only can they observe those processes directly in their everyday life, but they can see evidence of those processes as they walk around the schoolyard. For example, looking closely at concrete, they can see different size grains of sand held together with a grey material. As they look at these features, they realize that they can **ask questions** about the world around them and how it came to look the way that it does. Teachers can then introduce some natural geologic landscapes and

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[23] Schoolyard Geology, Lesson 3: http://education.usgs.gov/lessons/schoolyard

processes that act on Earth and relate them to analogous processes from construction on the schoolyard.

Earth scientists try to read layers of rocks like the pages of a history book. The composition and texture of each layer of rock reveals a snapshot of what the world looked like when that layer formed, and the sequence of layers reveals major events that reshaped them. In Earth science, these layers are the expression of the cross-cutting concept of ***structure and function***. While in life sciences and engineering, structures are specific shapes so that they can accomplish certain functions, in Earth science structure is often a direct consequence of the processes shaping the planet.

Each of these layers is built from material that came from somewhere else; this ***cycle of matter*** is referred to as the rock cycle. This instructional segment focuses on a portion of the rock cycle that occurs near the surface of the Earth where existing rocks are broken into pieces that are then moved around, reshaped, and combined back into a solid rock again. Rocks that are made directly from pieces of other rocks in these processes are called sedimentary rocks.

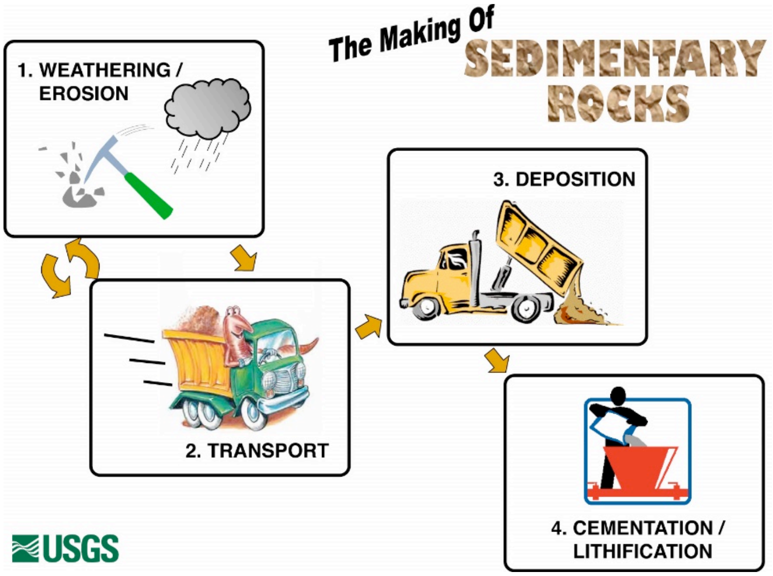

Figure 10. Processes involved in the making of sedimentary rocks. (USGS 2015)

Engineering connection: Cement and Sedimentary Rocks

Students may not realize it, but they are already familiar with sedimentary rocks because most materials in the built environment such as roads, sidewalks, bricks, and concrete are essentially artificial sedimentary rocks with small pieces of rock material cemented together. The average American is responsible for the use of nearly 9 tons of crushed rock material every year of his or her life (USGS 1999b). These artificial materials are carefully engineered to have sufficient strength at the lowest cost. Students can **obtain information** about where rock aggregate comes from in their community (it is very heavy and expensive to transport and usually quarried as locally as possible). The process of cementation of natural sedimentary rocks usually occurs slowly underground as mineral-rich water flows through pore spaces between grains, but it can be sped up by adding concentrated cement minerals and water in a concrete truck. To develop a **model** of how sedimentary rocks form (such as **Figure 10**; *MS-ESS2-1*), students can engage in an engineering challenge to create the most durable concrete from plaster of Paris and different size and shape rock pieces (sand, smooth pebbles, angular pebbles, etc…)[24]. They decide the ideal ***proportions*** to mix the materials in small paper cups. After letting their 'concrete' dry, they remove the paper cup and see whose material is strongest by piling on different amounts of weight or dropping it from different heights (*MS-ETS1-2*). This process helps motivate the rest of the instructional segment as it provides students a physical model for the steps of sedimentary rock formation as well as introducing them to the idea that rocks are broken down through the process of erosion.

Students are now ready to apply their **model** for how sedimentary rocks form to **constructing explanations** of how the Earth's surface has ***changed*** over time (*MS-ESS2-2*). The composition of the grains in a sedimentary rock matches the composition

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[24] A short snippet for this idea is at: http://www.rsc.org/Education/Teachers/Resources/Inspirational/resources/4.3.2.pdf

of the original source rock. For example, a rock formation called the Gualala conglomerate located near Point Arena in northern California contains large chunks of a rock that appears to match the composition of the Gold Hill/Logan Gabbro in central California. As rocks are transported by wind, water and gravity, the pieces are broken down smaller and jagged edges are smoothed out over time. The Gualala conglomerate has grains that are large, so they could not have traveled very far in a river before they were deposited and cemented into a solid rock. In this case, however, some pieces of the Gualala conglomerate are found hundreds of miles away from their matching source rock. In addition to the small amount of movement by water and gravity, scientists infer that these rocks were transported along half of California by the San Andreas fault over millions of years! Students can perform an **investigation** similar to these scientists by examining a sedimentary rock (in hand sample or photographs) and trying to match it to different potential source rocks. They will have to **plan the investigation** by deciding what features to observe in order to distinguish the different rocks and should consider things like the size, shape, and composition of the grains. This form of investigation where students are limited to observations and comparisons is common in Earth science where it is often difficult to manipulate variables and experiments because the time and spatial ***scales*** of Earth processes is so large.

There are situations where Earth scientists can perform **investigations** that simulate real-world processes at the small ***scale***. A stream table (a sloped table or plastic bin covered with sand and other earth materials and flooded with water) is a platform for exploration about erosional processes and is an example of both a hands-on **investigation** and a physical **model** that can be used to predict possible outcomes. Students can use a stream table to investigate the factors that affect how quickly material is broken off (weathered) and transported (eroded). When erosion is driven by the movement of water, the steepness of the slope has a huge impact on the rate of erosion because water builds up more kinetic ***energy*** when accelerating down a steep hill (PS2.A). As the water molecules collide with the soil and rock, they can dislodge individual pieces and carry them away. Students can also identify ***patterns*** in the shapes of landforms in the stream table that might be similar to local landforms, such steeply carved river channels that make meandering bends or wedge-shaped delta and alluvial fan deposits that form when the river reaches a flat section at the bottom of a steep slope.

Forecasting Erosion Hazards: Landslides

Landslides are a rapid form of erosion that can damage property and put peoples' lives at risk. Thankfully, areas that are most at risk for landslide hazard are easy to recognize: steep slopes made of loose sediments are most at risk. Landslides are also much more likely to happen during periods of intense rainfall, so their timing can be forecast as well. Students can qualitatively explore these risk factors using a stream table (a plastic tub filled with sand to represent Earth's surface and cups of water as agents of erosion). They can perform **investigations** varying slope steepness by changing the angle of the plastic tub, strength of different rocks by testing different mixtures of clay and sand, and different rainfall intensities by using water containers with different size holes. They can then **analyze data** from real landslides in their local area using a state database of historical landslide studies[25] (*MS-ESS3-2*). Depending on data availability in their area, their analysis could look for ***patterns*** in the sizes or locations of landslides in comparison to the steepness of slopes or the types of rocks. Because landslides tend to occur over and over again in the same regions, this type of historical data helps inform the creation of maps of landslide hazard produced by the state. Students can also **obtain information** from government agencies about efforts to provide real-time forecasts of landslides in California so that people can either instigate timely measures to reduce their hazard (these might include installing sandbags, pumping water, or evacuating)[26]. This discussion has important ties to instructional segment 3's discussion of weather patterns and the water cycle, but also to instructional segment 1's discussion of climate ***change***. In high school, students will explore how landslide hazards could increase due to climate change (*HS-ESS3-5*).

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[25] California Department of Conservation, Landslide and/or Liquefaction maps: http://www.quake.ca.gov/gmaps/WH/regulatorymaps.htm

[26] USGS, NOAA/USGS Demonstration Flash-Flood and Debris-Flow Early-Warning System: http://landslides.usgs.gov/hazards/warningsys.php

Depositing New Layers

Pieces of rocks and minerals, often called ‘grains’ when discussing rock formation, get transported by gravity or moving wind and water. Conditions can ***change*** such that there is no longer enough ***energy*** in these ***systems*** to continue to carry the pieces, so they settle out and are deposited. For example, water moves fast as it races down a steep hillside, but slows down when it reaches a lake or the ocean at the bottom. As the water slows down, bigger grains settle first because they take the most energy to move. In a classroom, the relationship between grain size and water velocity can be illustrated in a large bottle filled with sand, soil, and water. After being shaken, the largest grains of sand will fall out quickly, but the water at the top will remain muddy for hours. When left overnight, the water will slow down enough that even the fine grains will settle and leave clear, clean water at the top of the bottle. In nature, the deposition of layers also buries any dead organisms and lead to the formation of fossils. By looking at the types of organisms and the size of the grains, scientists can reconstruct the geologic conditions in which the layer formed (i.e., was it a steep slope, where the river meets the ocean, or far out to sea?). Sediment that is deposited later buries previously deposited layers like a row of brick is placed on top of previously laid bricks to construct a wall.

Observing how layers ***change*** within a vertical sequence allows scientists to track ***changes*** in the environment over time. The formation of mountain chains (that push up mountains and therefore increase erosion) and ocean basins (new places where rocks can settle out and be deposited) is gradual while volcanic eruptions, and asteroid impacts are more abrupt. Periods of glaciation and warming occur at intermediate timescales. ***Changes*** of all ***timescales*** are recorded as changes in the rock layers and the fossils trapped within them. From this progression of layers, geologists can reconstruct a timeline of the entire history of the Earth. Students likely have heard of the names of geologic epochs like Jurassic, but exposure to these names in middle school is distracting from the overall goal of using layers to determine the relative timing of major events in Earth’s history. For example, major extinction events are recorded in layers of rocks as decreases in the diversity of fossils around the world at the same period in geologic time. Students can **obtain information** from movies, informational articles, or other resources in order to **construct an explanation** of how evidence from layers of rock helped scientists identify a major event in geologic history (*MS-ESS1-4*). Examples with a strong California focus include the extinction of the dinosaurs 65 million years ago (a classic illustration of the nature of scientific discovery that follows the work of University of California scientists)[27], the eruption history of a supervolcano like Long Valley caldera in eastern California, or the history of past glacial periods determined by looking at layers in sediment cores taken from lakes in the Sierra Nevada mountains.

Sediment Deposition, Groundwater Flow, and Energy Resources

The storage and flow of groundwater depends greatly on the materials that make up the layers of rock and soil and how they formed. When layers of sediment are first deposited, there is space between individual grains that water can flow through like pores of a sponge. Sediment deposited in slowly moving water has small grains like silt and mud with small and poorly interconnected pore spaces, so water does not flow well through them. In environments where larger grains are deposited, the larger spaces between grains tend to be well interconnected and water can flow through them easily. Students can probably visualize dumping a bucket of water in a sandbox and having the water flow quickly downward into the sand, but a muddy soil prevents the flow of water and mud puddles can exist for hours after a rainstorm. A geologic setting where large particles are deposited will lay down consistent layers of material that enables groundwater flow. However, as the climate and environment ***change*** in cycles over time, one location can alternate between layers of small grains and layers with larger grains, interrupting the flow of water.

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[27] Useful resources include: Howard Hughes Medical Institute, The Day the Mesozoic Died: http://www.hhmi.org/biointeractive/day-mesozoic-died and University of California Museum of Paleontology, Understanding Science: Asteroids and dinosaurs: Unexpected twists and an unfinished story: http://undsci.berkeley.edu/article/0_0_0/alvarez_01

Students can combine their **models** of sediment deposition and groundwater flow to **construct an explanation** of how ancient geologic processes affect the present-day distribution of groundwater resources in California (*MS-ESS3-1*). **Figure 11** shows California's Central Valley, which has accumulated thousands of feet of sediment that eroded off the Sierra Nevada mountains during the last 100 million years. The sediments are not all the same, however. There was once a shallow sea covering the Central Valley, so only fine-grained sediments settled out to form layers. As plate movements and climate ***changed***, sea level changed and fast moving rivers flowing over the land brought larger sized grains. As rivers changed their courses over time, the size of grains being deposited at each individual location varied, leaving behind thin lens-shaped layers of fine-grained sediments that impede the flow of water. In some cases, these impermeable layers extend so far across the valley that they essentially separate different pockets of groundwater from one another. These different pockets of groundwater are a major source of water for farming in the Central Valley, especially in years of drought when rain and snow do not provide sufficient surface water. While the details differ, similar processes occur in other valleys of all sizes throughout the state. When students look at a map showing the location of groundwater wells throughout the state[28], they should recognize the ***pattern*** that the vast majority of them are on valley floors where layers of soft sediment have been recently deposited.

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[28] State Water Resources Control Board, Groundwater Ambient Monitoring and Assessment: http://geotracker.waterboards.ca.gov/gama/; USGS, National Water Information System Mapper: http://maps.waterdata.usgs.gov/mapper/index.html

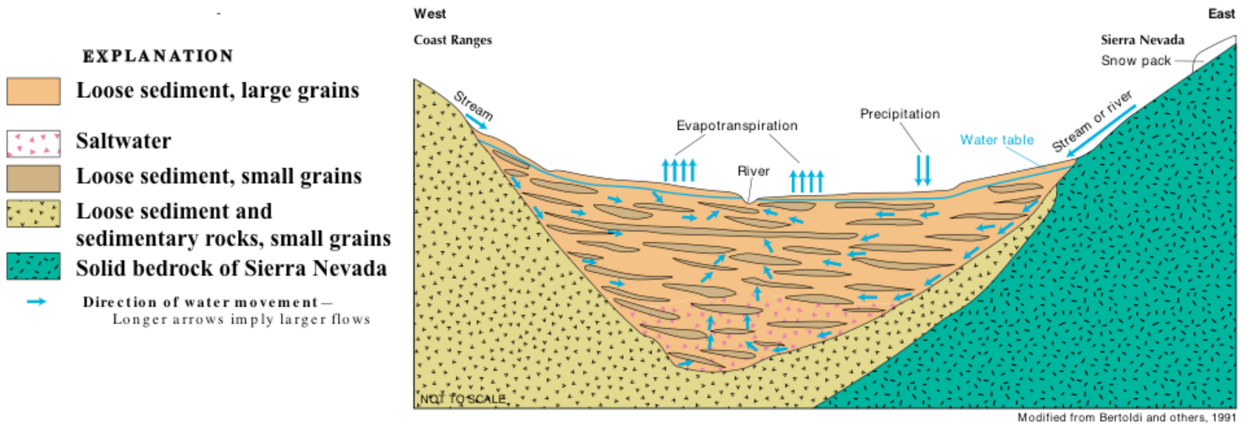

Figure 11. A slice through California's Central Valley emphasizing groundwater flow through sediment in the ground as part of the water cycle. Water flows easily through the loose sediment made of large grains but does not penetrate easily into the small-grained loose sediments or the rocks beneath them. Gravity causes water to flow downward on both sides of the valley, but gets pushed back up when these flows converge along the axis of the valley, contributing water to the rivers and marshland in the Valley. (USGS 2009)

Water is not the only important resource that can flow through rocks; students can apply the same conceptual **models** to **explain** how crude oil and natural gas flow through pore spaces in rocks and can become trapped by layers with low permeability (*MS-ESS3-1*). Scientists working for oil and gas companies study the geologic history of an area so that they can target their drilling towards pockets where oil and gas is trapped. These scientists must also consider whether or not the geologic history of an area includes the deposition of large amounts of organic material (dead organisms) along with the original sediments. That organic material will slowly ‘mature’ into oil or gas resources through a series of chemical reactions sped up by the heat and pressure of burial. The reason these ***energy*** resources are so valuable is that it is rare to deposit layers in the ideal sequence for creating and preserving them: first a layer with abundant organic materials needs to be deposited, then a layer with large pore spaces through which oil and gas can flow and accumulate needs to be deposited on top of that, and then a layer with tiny grains to block the flow of oil and trap it at the right depth underground where it can be preserved for millions of years.

In this instructional segment, students have focused solely on the development of layers of sedimentary rock near Earth's surface and their relationship to the destructive force of erosion. Many of the ***changes*** in what happens at the surface are in fact driven by major changes inside Earth (**Figure 12**). The next instructional segment focuses on those processes.

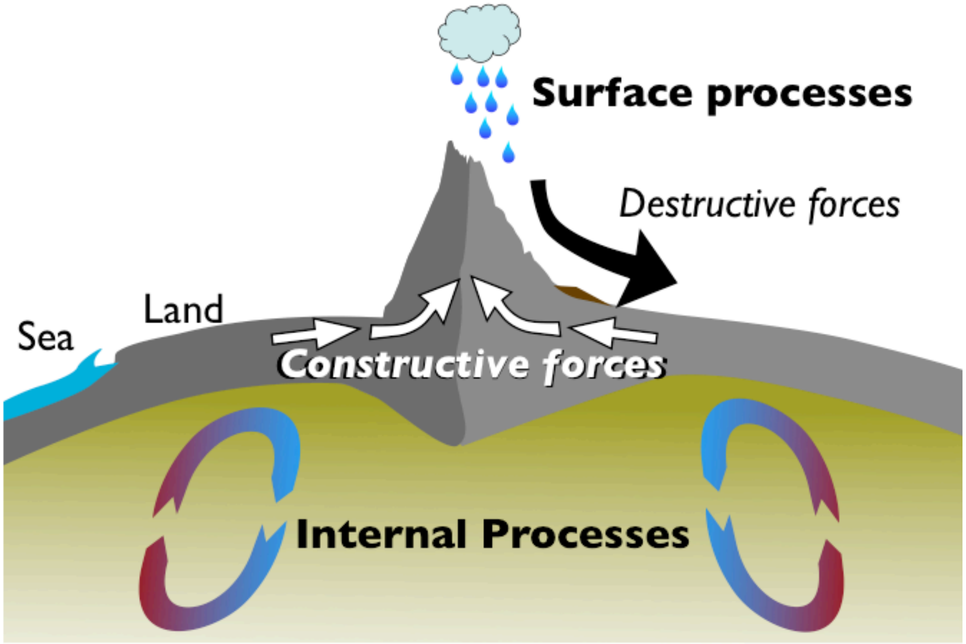

Figure 12. Landscapes are shaped at a range of timescales by processes inside the Earth and on the surface. Image credit: (CC-BY-NC-SA) by M. d'Alessio

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Grade 6 Instructional segment 5: Geosphere: Internal Processes

Instructional segment 5: Geosphere: Internal Processes

Guiding Questions:

- How can the shapes of landforms at the surface help us understand processes that are going on deep within the Earth?
- How can understanding plate motions help us locate resources (energy, mineral, and water) and protect ourselves from natural hazards?

Highlighted Scientific and Engineering Practices:

- Analyze and Interpret Data
- Develop and Use Models

Highlighted Cross-cutting concepts:

- Patterns
- Cycles of energy and matter

Students who demonstrate understanding can:

MS-ESS2-1. Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process. [Clarification Statement: Emphasis is on the processes of melting, crystallization, weathering, deformation, and sedimentation, which act together to form minerals and rocks through the cycling of Earth's materials.] [Assessment Boundary: Assessment does not include the identification and naming of minerals.]

MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. [Clarification Statement: Emphasis is on how processes change Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions), and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind. Emphasis is on geoscience processes that shape local geographic features, where appropriate.]

MS-ESS2-3. Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions. [Clarification Statement: Examples of data include similarities of rock and fossil types on different continents, the

	shapes of the continents (including continental shelves), and the locations of ocean structures (such as ridges, fracture zones, and trenches).] [Assessment Boundary: Paleomagnetic anomalies in oceanic and continental crust are not assessed.]
MS-ESS3-1.	**Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes.** [Clarification Statement: Emphasis is on how these resources are limited and typically non-renewable, and how their distributions are significantly changing as a result of removal by humans. Examples of uneven distributions of resources as a result of past processes include but are not limited to petroleum (locations of the burial of organic marine sediments and subsequent geologic traps), metal ores (locations of past volcanic and hydrothermal activity associated with subduction zones), and soil (locations of active weathering and/or deposition of rock).]
MS-ESS3-2.	**Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.** [Clarification Statement: Emphasis is on how some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions, but others, such as earthquakes, occur suddenly and with no notice, and thus are not yet predictable. Examples of natural hazards can be taken from interior processes (such as earthquakes and volcanic eruptions), surface processes (such as mass wasting and tsunamis), or severe weather events (such as hurricanes, tornadoes, and floods). Examples of data can include the locations, magnitudes, and frequencies of the natural hazards. Examples of technologies can be global (such as satellite systems to monitor hurricanes or forest fires) or local (such as building basements in tornado-prone regions or reservoirs to mitigate droughts).]
Significant Connections to California's Environmental Principles and Concepts: none	

Background and instructional Suggestions

If erosion were the only process sculpting Earth's surface, all of the mountains would eventually wear away. While some of the mountains on Earth do look smooth and rounded because erosion has flattened them out, others look sharp and jagged as though they have not been exposed and weathered for very long at all. Is there a process that somehow renews mountain ranges, pushing them up so that erosion will then tear them down?

In the early 1900's, a scientist named Alfred Wegener began looking at the locations of mountain ranges and noticed some ***patterns***. He saw that the Appalachian mountains were made of the same unique rock types as the Scottish Highlands across the Atlantic, and that a mountain range in South Africa was similar to one in Brazil. He **asked questions** about what could possibly explain the large present-day separation, so he considered the idea that all of Earth's continents could have been connected together millions of years ago and subsequently moved to their current locations. He gathered substantial **evidence** that supported this proposed **explanation** and he began to refer to the idea as "continental drift."[29] Some of this evidence came from using maps to show how well the continents fit together, especially including the submerged continental shelves in aligning the continents, and most obviously with South America and Africa.

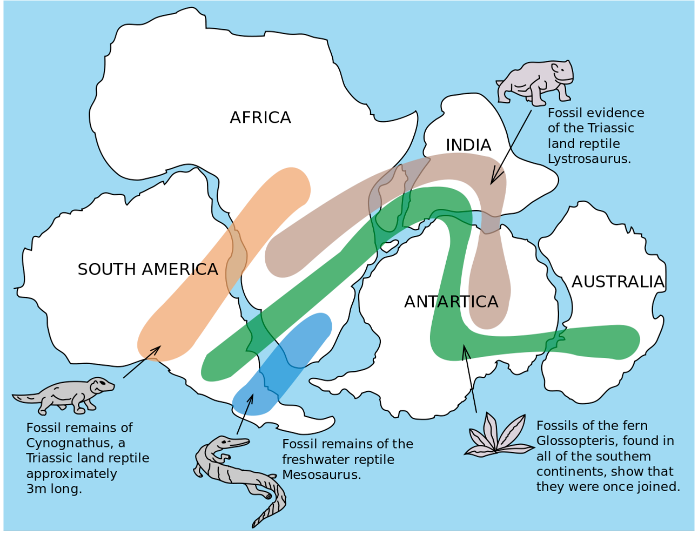

Figure 13. Fossil Evidence of Continental Drift. (USGS 1999a)

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[29] An English translation of Wegener's 1912 article outlines the full range of his evidence: Wegener, A. 1912. *Die Enstehung der Kontinente* [The origin of continents] (Trans. R. von Huene), Geol Rundsch 3, 276-292. http://www0.unsl.edu.ar/~bibliogeo/index_archivos/wegener.pdf

Even more persuasive was **evidence** from fossils and rocks. **Figure 13** shows continents from the Southern Hemisphere and how they could have been joined together hundreds of millions of years ago. The colored areas correspond to fossils whose specific geographic locations indicate not only that these continents were joined together, but also specifically that the connection points match those predicted by matching the outlines of the continents. The current wide separation of these continents precludes other easy explanations for the locations of these fossils.

Wegener also traced the past positions and motions of ancient glaciers based on grooves cut by those glaciers in rocks, and also by rock deposits that the glaciers left on different continents. His **evidence** indicated that if the continents had been in their current locations, the glaciers would have formed very close to the equator, an extremely unlikely situation. If the continents moved as he hypothesized, those glaciers would have formed much closer to the South Pole.

While we often say that Wegener compiled **evidence**, it is important to note that he built on the work of dozens of scientists of the day. At the time Wegener lived, there was no way to determine the exact age of rocks, but geologists could reconstruct the relative timing of events by correlating sequences of rock layers from one place to another (*MS-ESS1-4*, as discussed in instructional segment 4). Even though Wegener never visited the Andes and the Atlantic coast of South America, other geologists had written that folding of rock layers in the Andes mountain occurred at the same time as rifting apart of the Atlantic ocean. Wegener **obtained and evaluated the information** recorded by other scientists and then connected ideas in ways that nobody else had.

Despite the **evidence** that he compiled, Wegener's theory was not accepted and was generally forgotten. While Wegener was using traditional science practices of **analyzing data** and **constructing explanations** based on **evidence**, the other geologists were viewing his claims through the lens of the crosscutting concept of "***cause and effect: mechanism and prediction***." Wegener could not propose any possible mechanism that would cause continents to plow through the ocean over great distances. In the absence of a mechanism to cause the proposed movements of continents, the early twentieth century geologists rejected Wegener’s claims. Middle school students focus first on **analyzing the evidence** accumulated since Wegener’s time that provide even more definitive evidence that there has been motion of plates (*MS-ESS2-3*), then they develop a **model** relating that motion to the ***cycling of matter*** (*MS-ESS2-1*), and finally they can use that model to help explain ***changes*** in the Earth’s surface (*MS-ESS2-1*), the distribution of mineral resources (*MS-ESS3-1*), and to forecast the occurrence of natural disasters (*MS-ESS3-2*). In high school, they will look in more detail at some of the evidence and finally address the mechanism that drives all this motion (*HS-ESS2-1*, *HS-ESS2-3*).

Technological developments approximately 50 years later allowed detailed mapping of the shape of the sea floor, which revealed new information that supported Wegener’s claims and also provided the missing mechanism. Students can investigate undersea topography and notice ***patterns*** using a program like Google Earth. They can discover that the largest mountain ranges on the planet actually exist below the water of the ocean. One of the most obvious of these is the Mid-Atlantic Ridge, which rises about 3 km in height above the ocean floor and has a length of about 10,000 km running from a few degrees south of the North Pole down almost all the way to the Antarctic circle. While basically continuous across a huge part of the planet, it is far from straight. By tracing out the shape of the continental shelves on either side of the Atlantic and the axis of the Mid-Atlantic ridge, students can notice the ridge roughly parallels the turns of the coastlines. By measuring the distance from the center of the mountain range to the continental shelf, students can notice that the highest point of the mountains lies half way between the two coastlines, as if the two coasts were spreading apart from this central point. The idea that oceans were growing in size made it easier to understand how the continents could move away from each other.

With some ocean basins expanding, it didn’t make sense for the entire planet to be growing larger, so scientists began to look at how the growth could be balanced by the surface appearing to get smaller in other locations. Scientists had long recognized **evidence** for shortening on Earth because of evidence from sedimentary rock layers. In instructional segment 4, students created a **model** for how sedimentary rocks form in flat layers, but these layers are often observed to folded and curved, which could only happen by some sort of squeezing that would push up mountains. At the time Wegener lived, the only process that scientists could conceive of that could cause such squeezing was the overall contraction of the Earth as it cooled after being formed long ago. If the seafloor was known to spread at some locations, it makes sense that plates must crash together at others. This would explain why mountain ranges formed long bands perpendicular to the spreading directions. For example, the Andes mountains are not oriented randomly – they are at exactly the orientation you would expect if South America was spreading away uniformly from the Mid-Atlantic Ridge and crashing into the Pacific ocean on the other side. Seafloor structures also give one more key piece of **evidence** about plate motions: there are very deep canyons in the ocean that parallel coastlines and island chains in many locations. Just off the west coast of South America, students can notice a very deep trench in the ocean floor. A physical **model** with two foam blocks (or even notebooks) representing plates helps illustrate why such a trench might form when one of the plates sinks down beneath the other. It is just a simple consequence of the geometry of a bending block, with the trench forming at the inflection point where the down going block starts to curve. Students can use maps of global topography and bathymetry to see if they notice any ***patterns*** between the location of these deep sea trenches and their relationship to continents, mountain ranges, and islands.

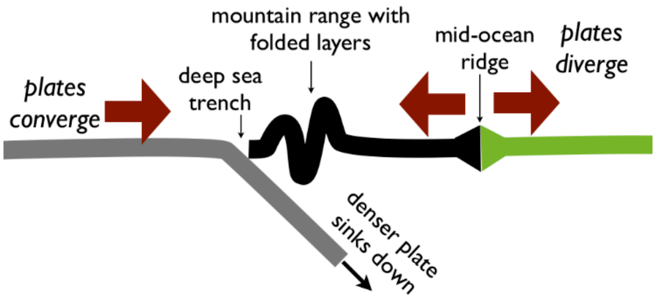

Figure 14. Schematic slice through the Earth's lithosphere showing three different plates with key seafloor and land features caused by their motion. Credit: (CC-BY-NC-SA) by Matthew d'Alessio

Taken together, the fit of the continental shelves, the separation of similar rocks and fossils across vast oceans, the location of mid-ocean ridges running precisely along the center of oceans basins, the location of deep sea trenches along the coasts of some continents are strong **evidence** that plates move apart at some locations, together at others, and sliding past one another in other locations. These motions are the driving forces for a wide range of processes that shape earth's surface and cause interactions with the anthrosphere.

Plate tectonics drives the rock cycle

One of the most important effects of plate motions is the ***cycling of matter*** that accompanies the motion. The geoscience processes that form rocks and minerals include: volcanic eruptions, the heating and compaction of rock deep underground, the cooling of very hot underground rock, the evaporation of mineral-rich water, and the physical and chemical breakdown of surface rock by wind and water. All but the last of these geoscience processes are driven by the transfer of Earth's internal thermal ***energy***. This internal thermal energy resulted from the immense heating of Earth's interior during its cataclysmic formation billions of years ago, the gravitational compaction of Earth in its early history, and the energy released by radioactive decay of buried Earth materials. In high school, students will develop a model that relates these heat transport processes to the driving motions of plate tectonics (*HS-ESS2-3*).

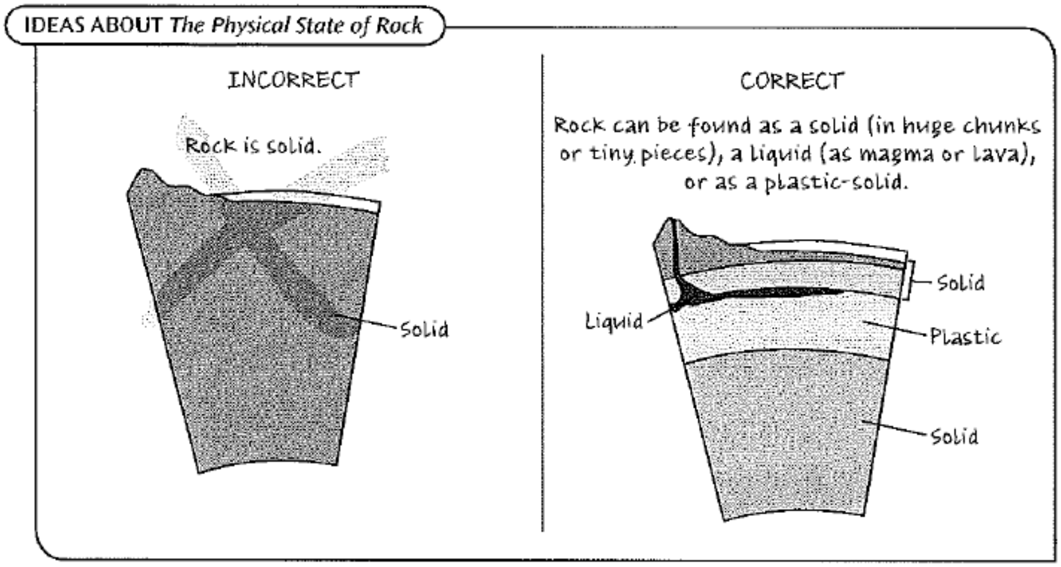

Figure 15. Ideas about the Physical State of Rock. Image Credit: Used by permission of WestEd Making Sense of Science project.

Rock at Earth's surface is almost exclusively a solid, except the few locations where it flows as liquid lava. As shown in **Figure 15**, liquid rock is also located underground, where it is called magma. Even in that illustration, the amount of liquid is exaggerated for visual effect. A significant percentage of the rock underground exists in a form that acts similar in some ways to a common children's toy, silicone putty. It is not clearly a solid or a liquid. This phase of matter is sometimes called a 'plastic solid' because it slowly flows and deforms under pressure like a liquid but retains its shape like a solid. Even deeper underground, the immense pressure causes the rock to exist as a solid.

Common Core Connection

Sometimes, everyday language differs from scientific language and can lead to confusion. In **Figure 15**, the word 'plastic' refers to an easily shaped material. This definition existed in dictionaries long before the invention of petroleum-based plastics that we use so commonly in everyday materials like beverage bottles or bags. The modern material called 'plastic' earned its name because it could be easily melted and formed into different shapes. (CA CCSS for ELA/Literacy L.6.6)

Many of the ***changes*** that happen to the geosphere (Earth's nonliving solid material excluding ice) are due to movement of tectonic plates. As the plates push together, spread apart, and slide against one another, a variety of geologic processes occur including earthquakes, volcanic activity, mountain building, seafloor spreading, and subduction (sinking of a plate into the underlying mantle). All of these geoscience processes change Earth's rock – some form new rock, and others break down existing rock.

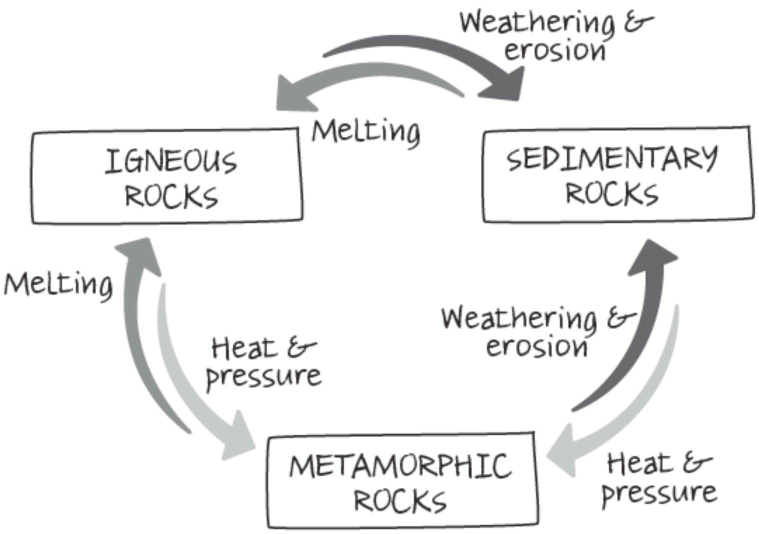

Figure 16. Classic Rock Cycle Diagram. Image credit: Used by permission of WestEd Making Sense of Science project.

These physical and chemical transformations of rock are often summarized as the rock cycle. **Figure 16** shows a classic rock cycle diagram with the three major rock types of igneous (melted in Earth's interior), sedimentary (compacted from broken pieces), and metamorphic (rearranged by Earth's internal pressure and thermal energy).

As summarized in

Table 3, the classic rock cycle diagram is a good summary of some of the key interactions of the geosphere. However, like most **models**, it has inaccuracies and can foster preconceptions. Students can mistakenly surmise that every rock has experienced or will experience the same cycle. However, rock does not move through the "rock cycle" in a specific order, like a product on a conveyor belt moving through a factory. The Geological Society in Britain has a very useful rock cycle website at http://www.geolsoc.org.uk/ks3/gsl/education/resources/rockcycle.html. This website is a very useful resource for students, who could then be challenged to find California examples of the British rocks and landforms.

Table 3. Benefits and Limitations of Classic Rock Cycle Diagram

Benefits	Limitations
Good summary of key geosphere interactions.	Does not show the many interactions the geosphere has with other Earth systems.
Easy to read and understand.	Does not show the timeframe for each geologic process, implying that they have similar timeframes.
Shows how each type of rock can become the other types of rock.	Does not show the locations where each geologic process takes place.
Helps dispel the incorrect idea that rock is “steady as a rock” and never changes.	Suggests that rock never leaves the rock cycle. Yet rocks often do leave the rock cycle, such as when they are incorporated into organisms, other Earth systems, and human-made materials.

Table used by permission of WestEd Making Sense of Science project.

The physical and chemical ***changes*** that happen to minerals and rocks reinforce the principle of the ***conservation of matter***. Almost three-quarters of Earth’s crust is made of oxygen and silicon. Just six elements (aluminum, iron, magnesium, calcium, sodium, and potassium) make up practically all the rest of Earth’s crust. Atoms of these eight elements combine to form Earth’s rocks and minerals. Throughout all the physical and chemical interactions, none of these atoms are lost or destroyed. Even as the appearance and behavior of the rocks ***change***, their overall composition remains ***stable***.

Students can demonstrate that they understand the relationship between plate motion and the rock cycle by placing different types of rocks on an illustration showing typical plate boundaries (*MS-ESS2-1*, *MS-ESS2-2*). Magma solidifies to form igneous rocks at places where magma can reach the surface such as mid-ocean ridges. Rocks experience increases in temperature and pressure that can transform them into metamorphic rocks as they are dragged deep into the Earth when plates collide. Sedimentary rocks form all over Earth's surface, but especially in zones where mountains are actively being pushed up where plates collide.

Plate Tectonics and Resources

Plate tectonics plays an important role in the uneven distribution of Earth's natural resources (*MS-ESS3-1*). Volcanic and uplift processes can bring important minerals on or near the surface where they can be profitably mined. For example, students can compare the location of the world's largest copper mines to the location of plate boundaries and see that there is a general ***pattern***: mines are often located near plate boundaries. The prospector's shout that "there's gold in them thar hills" directly connects gold distribution with the plate tectonics that created them thar hills.

Fossil fuel distribution is one the most politically important uneven distributions of natural resources, and it is also tied to plate tectonics. The Middle East has about 2/3 of the world's proven reserves of crude oil. Petroleum and natural gas are generally associated with sedimentary rocks. These fuels formed from soft-bodied sea organisms whose remains sank to the ocean floor, decomposed in the relative absence of air, and were further transformed by heat and pressure deep underground. Even areas on dry land today can be the sites of ancient ocean basins that have been uplifted by plate collisions. These same collisions can deform the rock layers in ways that allow oil and gas to accumulate in concentrated locations (where they can be easily extracted) and remain trapped there for millions of years. Students will **investigate** this process in high school.

Plate boundaries are often places where hotter material rises up from Earth's interior to near the surface. This heat can be harnessed to generate electricity and as a source of ***energy*** for heating buildings and commercial purposes. California is home to some of the world's largest geothermal power plants, with production in both northern and southern California that provide a total of 6% of the state's electricity (with potential for even more). Other western states also utilize geothermal resources, but there are no geothermal power plants east of North Dakota in the US, largely because these areas are far from plate boundaries.

In instructional segment 4, students learned about groundwater as an important resource as water percolates into the spaces between pores in sediments and rock. The distribution of groundwater basins is also affected by plate motions. The best groundwater basins are in valleys where a large amount of sediment has continuously been deposited, such as the Central Valley receiving sediment from the Sierra Nevada mountains. Plate motions typically determine the shapes of these basins and are the cause of mountains being uplifted in the first place. The faster they are pushed up, the faster they erode (because rapid uplift produces steep slopes that erode quicker). Of course, groundwater also requires an abundant source of water. In addition to the important latitudinal controls on precipitation discussed in instructional segment 1, mountains have a strong impact on where precipitation occurs; moist air flowing up mountains tends to precipitate on the windward side of the mountains leaving a rain shadow further downwind. The mountains that ‘squeeze moisture out’ are often recently uplifted by plate motions.

Understanding Plate Motions Allows Hazard Mitigation

In 4th grade, students analyzed ***patterns*** in maps and may have **investigated** the distribution of earthquakes on the planet (4-ESS2-2). With an understanding of the patterns of plate motions and previous events, scientists are better able to forecast natural disasters such as earthquakes and volcanoes. The process is somewhat analogous to asking students to predict where in California it will snow next January. With a basic understanding of the patterns of geography, they could very reliably identify places where it will almost certainly not snow (downtown Los Angeles, for example) and where it is more likely to snow (perhaps along the high peaks in the Sierra Nevada mountains). Whether it actually snows during that month depends on specific physical processes, such as the location of the jet stream, which are difficult or impossible to predict far in advance. Earthquakes occur because friction causes plates to stick together where they touch. Even though forces deep within the Earth try to pull them along, the plates remain stuck until the strain builds up so much that they suddenly slide past one another in a single violent lurch. Students can build a physical

model of this process with a brick, a bungee cord, and sand paper[30], or explore a virtual physical model using an online simulator[31]. Scientists can monitor the amount of strain built up along plate boundaries using high precision GPS and can calculate the amount of strain that is likely to be released in the next large earthquake at different locations. In other words, scientists can predict where earthquakes could be and how big they could be with relatively high reliability. State and local authorities have published maps showing the likelihood of different size earthquakes in locations throughout California[32]. Students could use this map to hold a mock session of the state legislature debating the allocation of earthquake preparedness funding. Different students representing different districts around the state use information about their population, their economic contributions, and the earthquake forecasts to **argue** that their district is deserving of a larger share of the funding.

The only part of the process that is not yet predictable is the exact timing of the earthquakes. While scientists have **investigated** a wide range of monitoring strategies, it appears that many earthquakes occur without any perceivable trigger. That means that the soonest we can know about earthquakes is the moment that they first start. Earthquake waves do take time to travel through the Earth, so there is one more way that understanding earthquakes can help us mitigate their effects. The moment a seismic recording station detects shaking, it can send a signal at the speed of light to a central processing center that can issue a warning of the impending earthquake. Such warnings can be distributed to schools, businesses, and individuals via the internet, mobile phones, and other broadcast systems, providing them warning of a few seconds to a minute. Such systems have been in successful operation in Japan and Mexico City, and a prototype is being tested in California. After investigating ***patterns*** of earthquake occurrence in their region, students can make decisions about where to place seismic recording devices to design their own earthquake early warning network that provides

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[30] SERC, Earthquake Demonstration: http://serc.carleton.edu/introgeo/demonstrations/examples/earthquake.html

[31] CSUN, The Earthquake Machine: http://www.csun.edu/quake/eqmachine

[32] USGS. UCERF3: A New Earthquake Forecast for California's Complex Fault System, USGS Fact Sheet 2015-3009: http://pubs.usgs.gov/fs/2015/3009/pdf/fs2015-3009.pdf

the maximum advance warning (*MS-ESS3-2*) (d'Alessio and Horey 2013). Using an online simulator[33], students test their network's performance in sample earthquakes, compare network designs with their peers (*MS-ETS1-2*) and iteratively improve them (*MS-ETS1-3*).

Engineering Connection

Common Core Connection

Students can use simple equations of distance, speed, and time to calculate the amount of warning they can expect when a seismic recording station is a given distance away from the earthquake source (*CA CCSSM* 6.EE.2.c, 6.EE.7).

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[33] CSUN, Earthquake Early Warning Simulator: http://www.csun.edu/quake